# Design and Control of a Hybrid Power System for a Remote Telecommunication Facility in Nigeria


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# Overview:

1. Introduction and Literature Review
2. Objectives of the Study
3. Optimal Sizing of the Hybrid System
4. Dynamic Modeling and Simulation of the system
5. Low-Cost Open Source SCADA system Design
6. Summary and Conclusions
7. Recommendations for future studies
8. List of Publications
9. Acknowledgments
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# Introduction:

## Nigeria's Power Sector:

- Installed Capacity 12,522 MW
- Utilized Capacity ~ 4000 MW for 206.1 million people
- Mostly Thermal and Hydro
- Less than 50% of customers metered

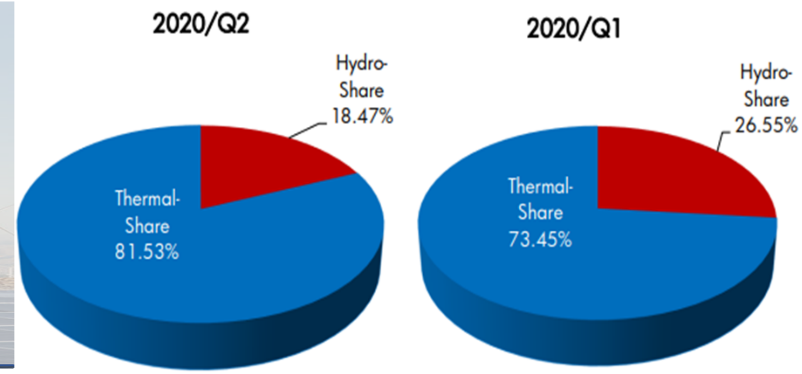



Fig. 2: Quarterly Share (%) of Electricity Generated

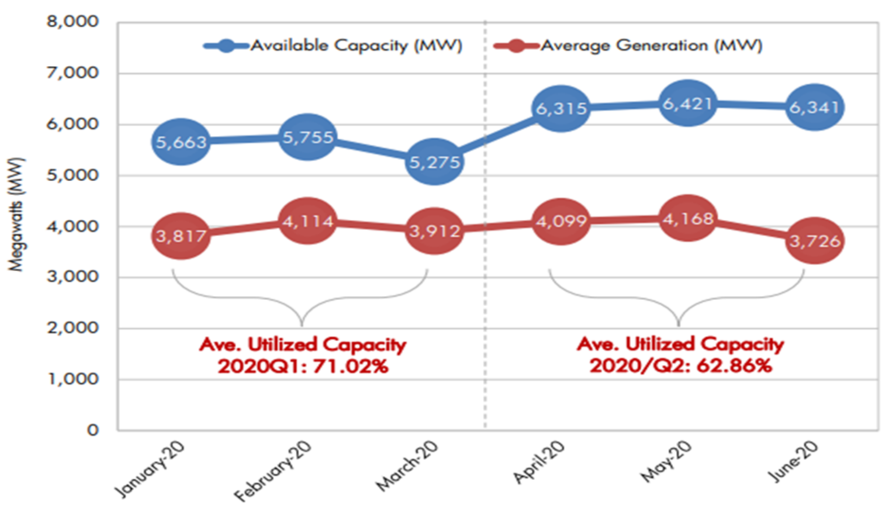



Fig. 1: Average Daily Generation and Available Capacity 2020/Q1-Q2

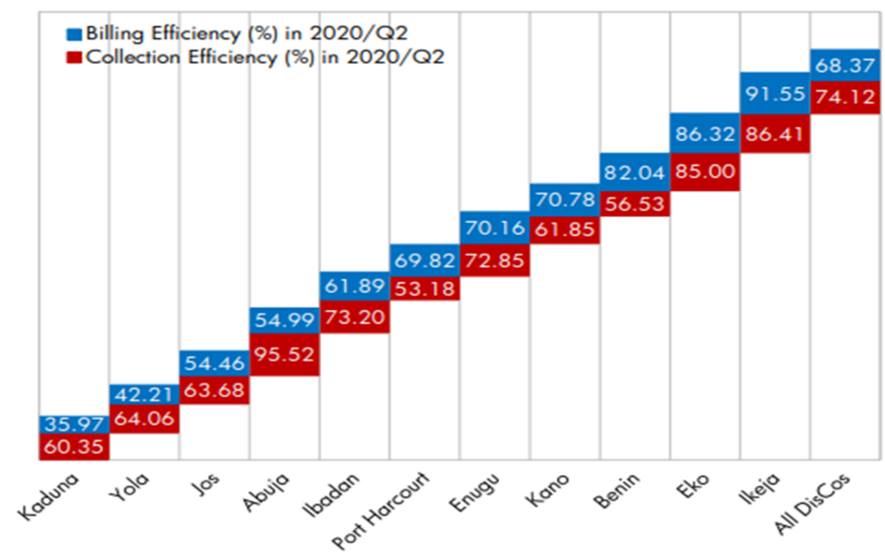



Fig. 3: Billing and Collection Efficiency by DisCos in 2020/Q2

# Introduction: Nigeria's Telecommunication Sector Data

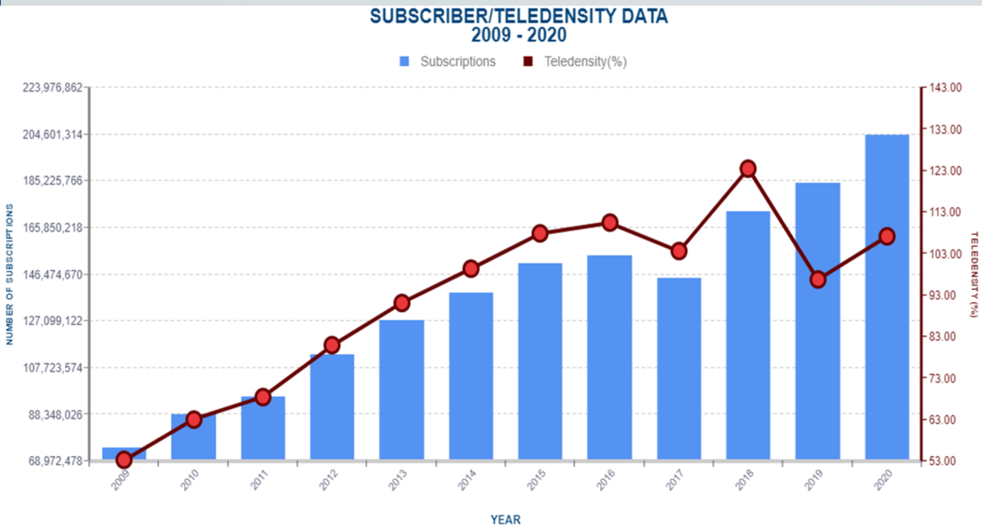



Fig. 4: Number of subscribers and teledensity of Nigeria between

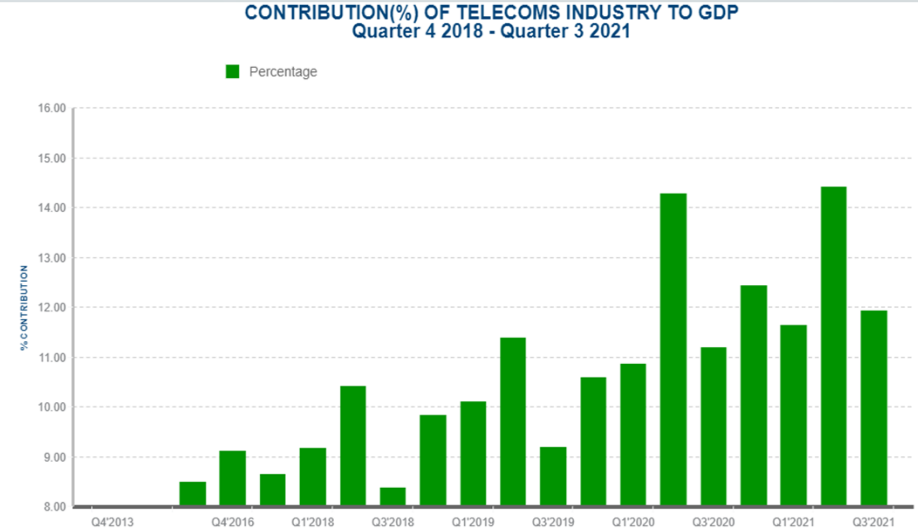



Fig. 5: Percentage(%) Contribution of Telecoms Industry to GDP

- Subscribers increase by 10.78% between December 2019 and December 2020 (19,901,904 Subscribers)
- Teledensity increased from 96.76% to 107.18%
- GDP contribution increased from 10.60% in Q4 2019 to 12.45% in Q4 2020
- 52,160 BTS and colocation towers in Nigeria

# Introduction: Renewable Energy Potential of Nigeria

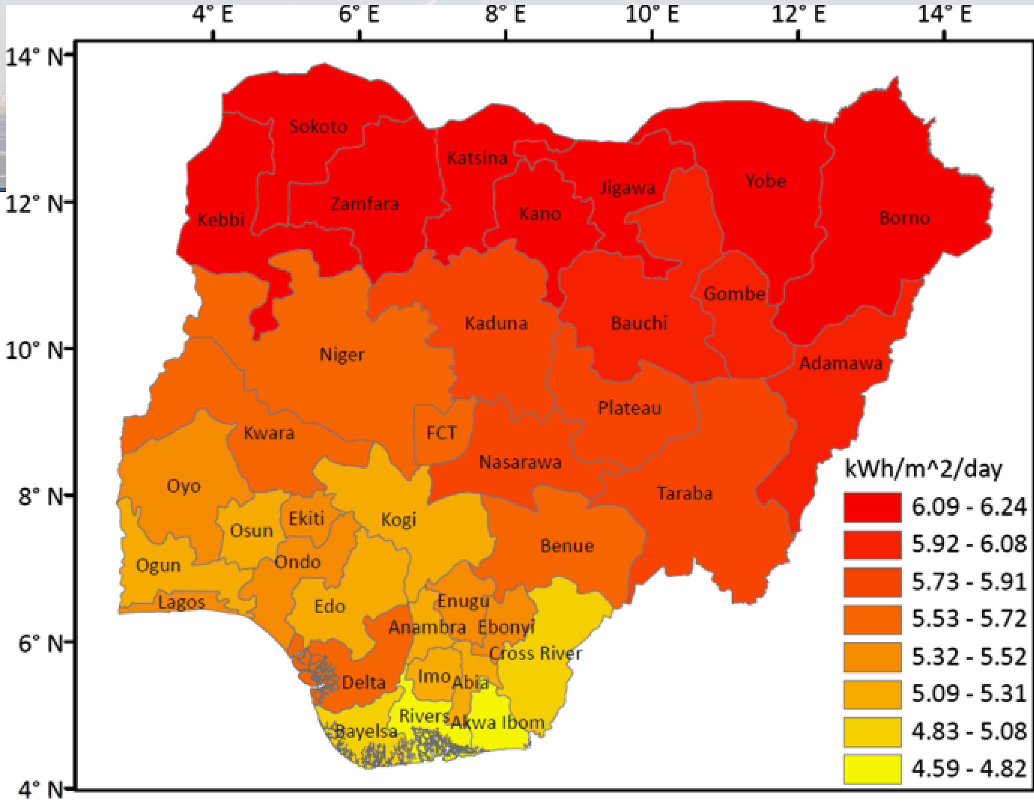



**Fig. 6: Map of Nigeria indicating the global solar radiation**

- ❖ Solar Energy Potential 427 GW (< 5 GW currently)
- ❖ Large Scale Hydro potential, 14,120 MW, Capable of 50,832 GW annually
- ❖ Small Hydro Potential, 3,500 MW (< 1.7% developed)
- ❖ Potential for Onshore and Offshore wind power generation

# Objectives of the Study:

- ❖Design an optimally-sized standalone hybrid power system using an existing load information, to replace the current diesel generator system being used in a rural telecommunication site in Nigeria
- ❖To analyse the savings in operational expenditure (OPEX) and the amount of green house gas emissions curbed by using this hybrid system over the conventional diesel generator that is being used currently.
- ❖To build and simulate a dynamic model in MATLAB/Simulink based on the HOMER pro sizing result to study the transient behaviour of the system under varying environmental and load conditions.
- ❖Design a low-cost Open Source SCADA System to monitor and measure relevant parameters in the hybrid power system and perform supervisory control.

# Optimal Sizing of the Hybrid System: Site Description


Fig. 7: Physical and satellite image of site

- ❖ Agbaja is located on Lat. 7° 59’ N & Long. 6° 39’ E
- ❖ Only two seasons (Dry and Rainy Season)
- ❖ The people are predominantly farmers with no grid power supply


Fig. 8: Site Elevation

# Optimal Sizing of the Hybrid System: Site Load

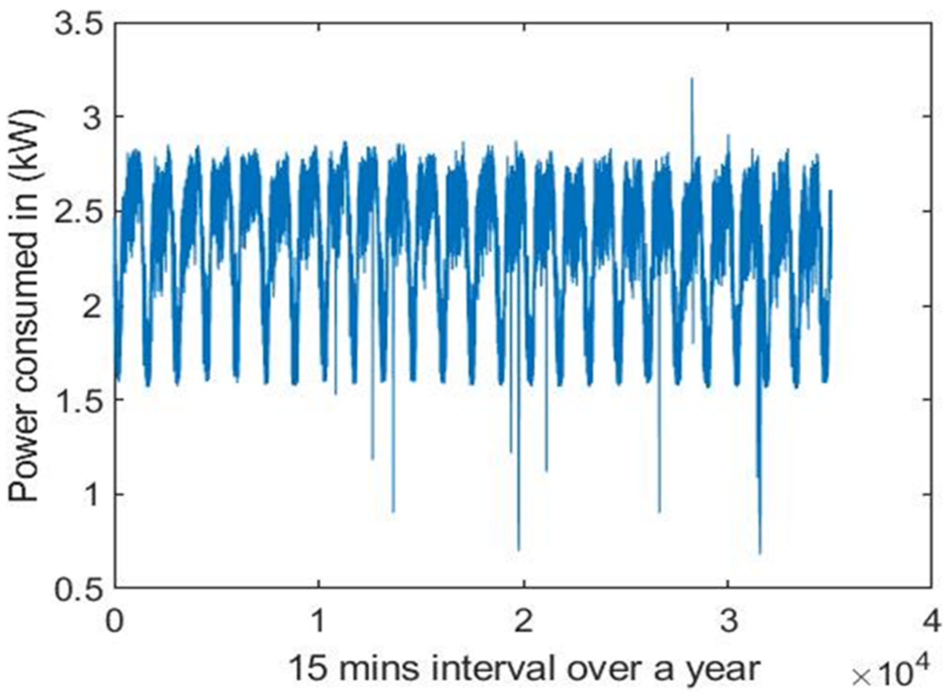



Fig. 9: Measured Site load for 1 year

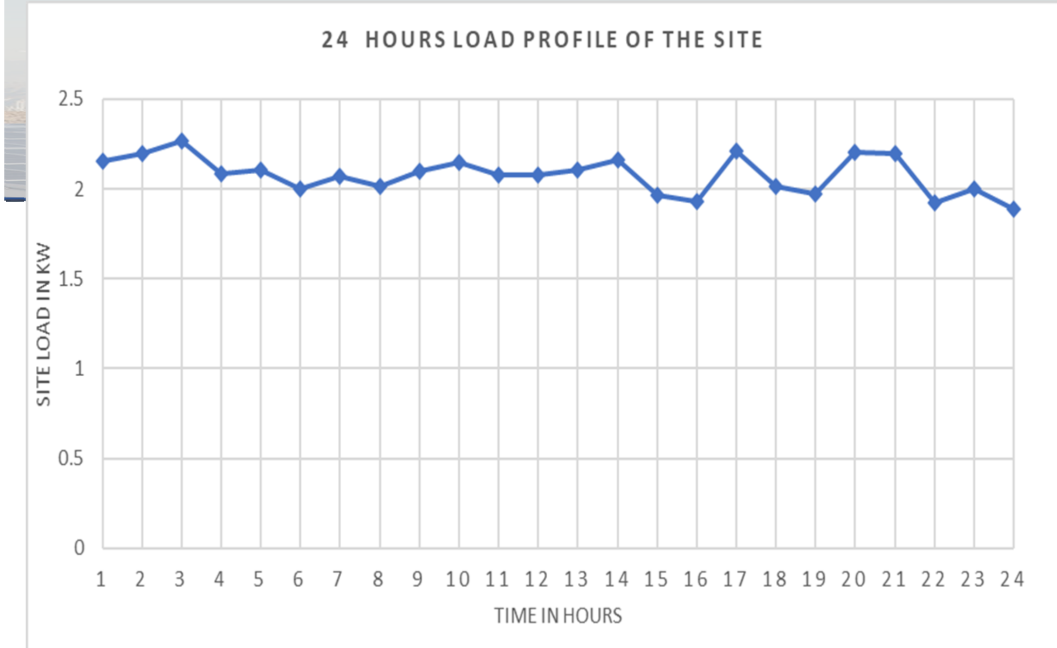



Fig. 10: Measured hourly load profile of the Site

# Renewable Resources at the Site

Table 1: Monthly Average Solar Irradiance

| Month | Clearness Index | Daily Radiation kWh/m²/day |
|---|---|---|
| Jan | 0.631 | 5.77 |
| Feb | 0.598 | 5.84 |
| Mar | 0.553 | 5.71 |
| Apr | 0.517 | 5.42 |
| May | 0.499 | 5.13 |
| Jun | 0.466 | 4.70 |
| Jul | 0.427 | 4.34 |
| Aug | 0.399 | 4.13 |
| Sep | 0.420 | 4.33 |
| Oct | 0.487 | 4.80 |
| Nov | 0.585 | 5.40 |
| Dec | 0.628 | 5.59 |

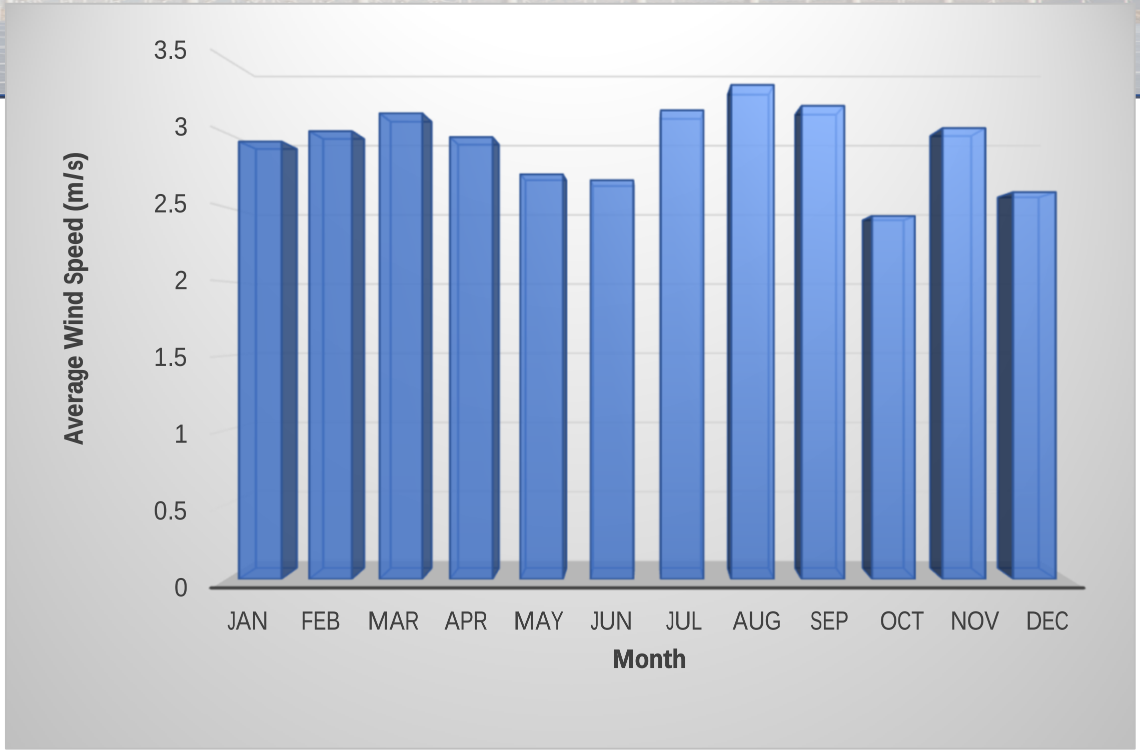



Fig. 11: Monthly average wind speed data

# HOMER pro Sizing

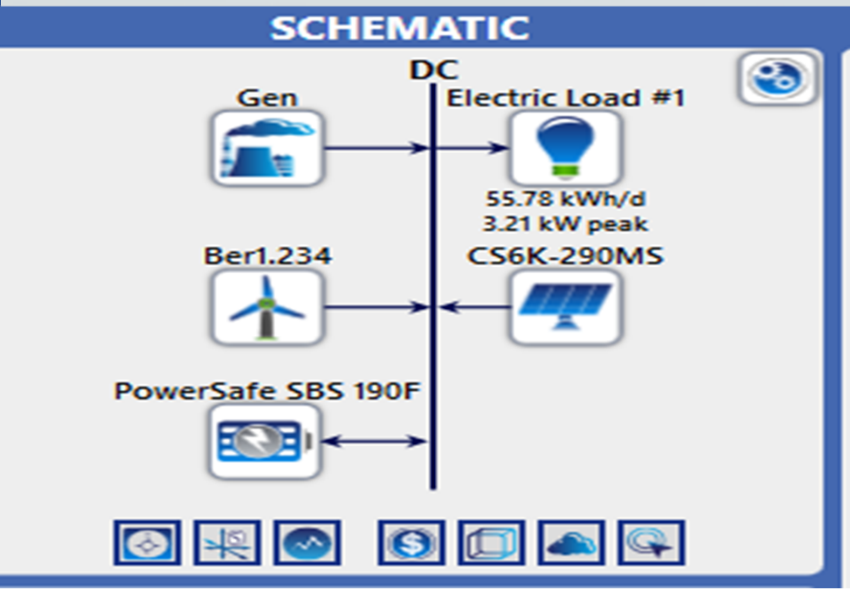



Fig. 12: HOMER pro Schematics

- DC coupled system
- DC diesel generator as back-up power

**Table 2: Specification of system components**

| | |
|---|---|
| **Solar Photovoltaic** | |
| Model Number | CS6K – 290MS |
| Nominal Maximum Power ($P_{Max}$) | 290 Watts |
| Module Efficiency | 17.72% |
| Derating factor | 88% |
| Lifetime | 25 years |
| Cost per kW | $1,000 |
| **Backup Battery** | |
| Model | EnerSys PowerSafe SBS 190F |
| Rating | 12 V, 190 Ah |
| Nominal capacity | 2.57 kWh |
| Roundtrip Efficiency | 97% |
| Throughput | 2,747.70 kWh |
| Cost per unit | $400 |
| **Wind Turbine** | |
| Model | Bergey BWCXL1 |
| Rated Capacity | 1 kW |
| Lifetime | 20 years |
| Cut-in speed | 2.5 m/s |
| Cost | $6,800 |
| **Diesel Generator** | |
| Model | Polar Power 8080P – 40205 |
| Rating (Continuous) | 3.6 kW |
| Output DC Voltage | 12 – 96 V |
| Engine's RPM | 2900 rpm @ 5.5 kW |
| Efficiency | >85% |
| Cost | $4,400 |

# Key Simulation Constraints:

- ❖ The lifetime of the overall system is 15 years.
- ❖ Nominal discount and inflation rates are taken as 12% and 13%, respectively, consistent with the country's current value.
- ❖ Capacity shortage is zero to ensure reliability.
- ❖ Abrupt load variation is accounted for by incorporating a 10% reserve.
- ❖ Load following (LF) dispatch strategy is adopted to harness the renewable resources available to charge the battery

# Homer pro System Simulation Results

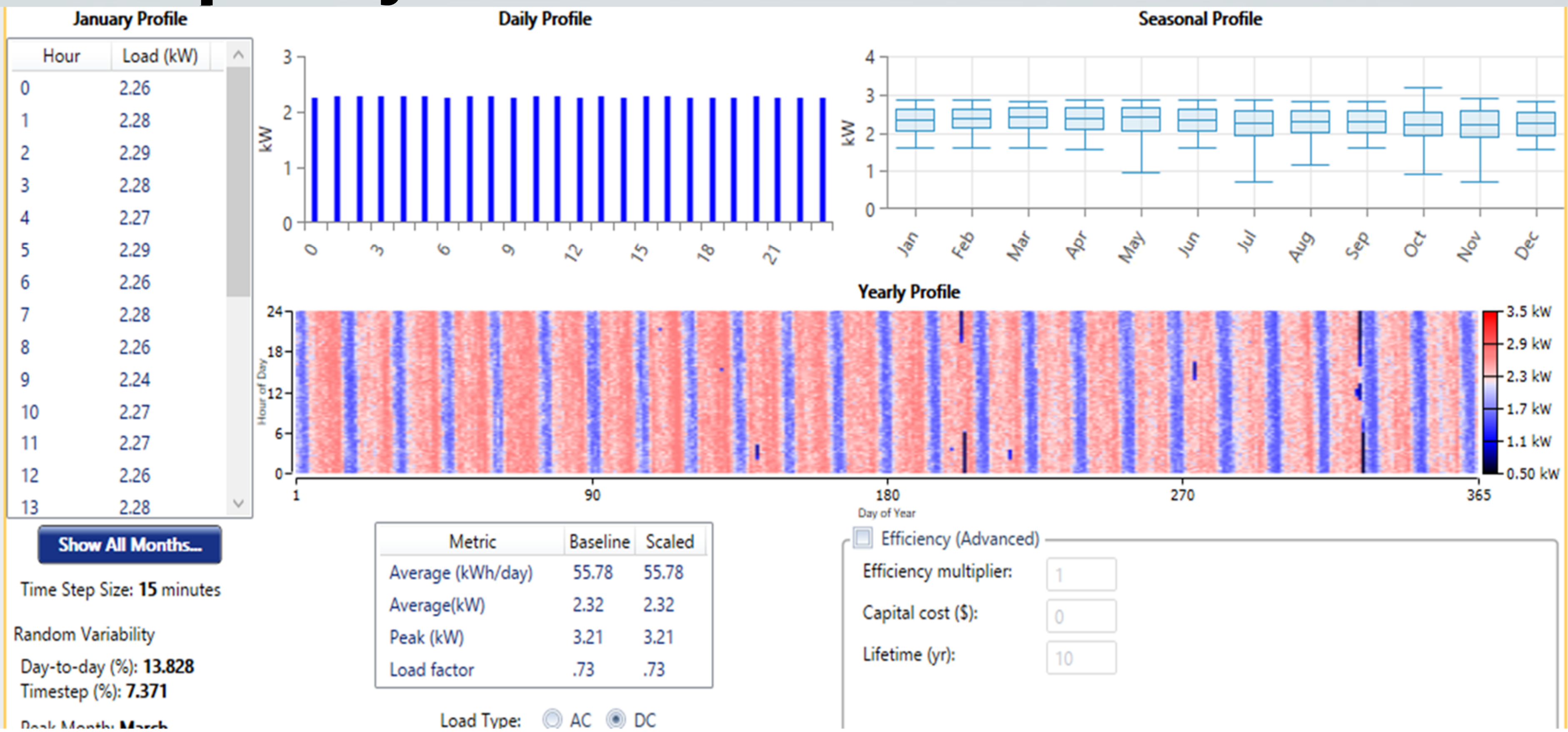



Fig. 13: Load Profile of the site on HOMER Pro

# Homer pro System Simulation Results

Simulation Results

| | |
|---|---|
| System Architecture: | EnerSys PowerSafe SBS 190F (6.00 st |
| CanadianSolar All-Black CS6K-290MS (15.0 kW) | HOMER Load Following |
| Autosize Genset (3.60 kW) | |

| | |
|---|---|
| Project Lifetime (15.00 years) | |
| Total NPC: | $44,342.73 |
| Levelized COE: | $0.2225 |
| Operating Cost: | $1,722.91 |

CanadianSolar All-Black CS6K-290MS | Emissions
Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | Autosize Genset | Renewable Penetration | EnerSys PowerSafe SBS 190F

| Production | kWh/yr | % |
|---|---|---|
| CanadianSolar All-Black CS6K-290MS | 23,213 | 91.5 |
| Autosize Genset | 2,150 | 8.48 |
| Total | 25,363 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 0 | 0 |
| DC Primary Load | 20,360 | 100 |
| Deferrable Load | 0 | 0 |
| Total | 20,360 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 4,720 | 18.6 |
| Unmet Electric Load | 0 | 0 |
| Capacity Shortage | 0 | 0 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 89.4 | % |
| Max. Renew. Penetration | 1,200 | % |

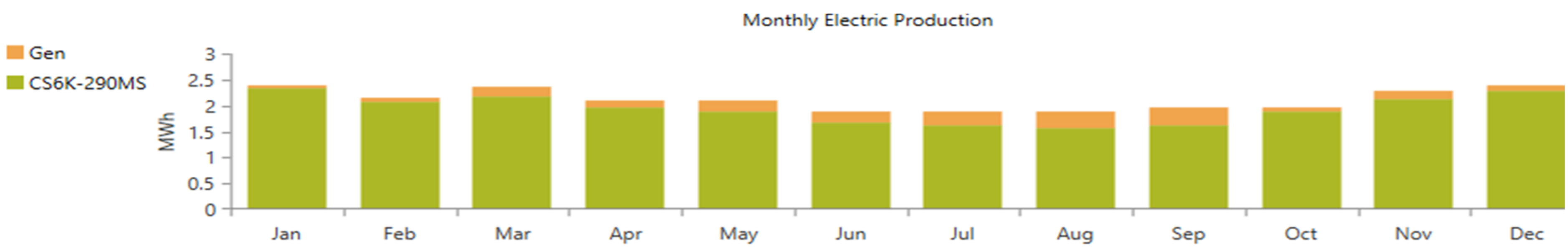



**Fig. 14: HOMER pro electrical summary for the system**

# Homer pro System Simulation Results

| Quantity | Value | Units |
|---|---|---|
| Batteries | 24.0 | qty. |
| String Size | 4.00 | batteries |
| Strings in Parallel | 6.00 | strings |
| Bus Voltage | 48.0 | V |

| Quantity | Value | Units |
|---|---|---|
| Autonomy | 18.6 | hr |
| Storage Wear Cost | 0.148 | $/kWh |
| Nominal Capacity | 61.8 | kWh |
| Usable Nominal Capacity | 43.2 | kWh |
| Lifetime Throughput | 65,945 | kWh |
| Expected Life | 6.70 | yr |

| Quantity | Value | Units |
|---|---|---|
| Average Energy Cost | 0 | $/kWh |
| Energy In | 9,978 | kWh/yr |
| Energy Out | 9,695 | kWh/yr |
| Storage Depletion | 16.7 | kWh/yr |
| Losses | 300 | kWh/yr |
| Annual Throughput | 9,844 | kWh/yr |

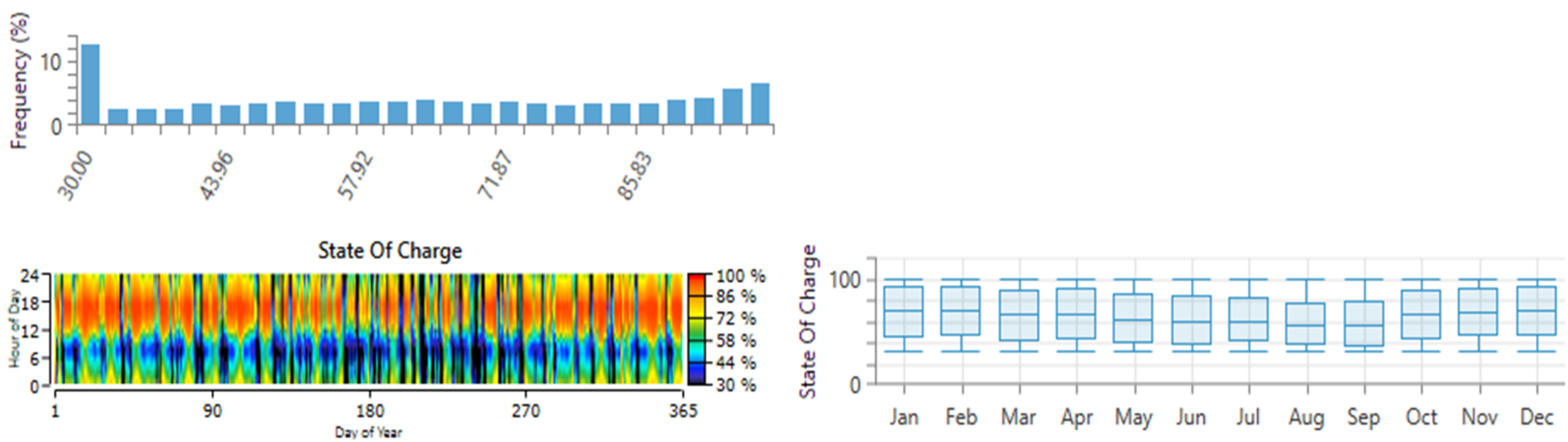



Fig. 15: HOMER pro Battery summary for the system

# Homer pro System Simulation Results

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 1,181 | hrs/yr |
| Number of Starts | 125 | starts/yr |
| Operational Life | 16.9 | yr |
| Capacity Factor | 6.82 | % |
| Fixed Generation Cost | 0.393 | $/hr |
| Marginal Generation Cost | 0.165 | $/kWh |

| Quantity | Value | Units |
|---|---|---|
| Electrical Production | 2,150 | kWh/yr |
| Mean Electrical Output | 1.82 | kW |
| Minimum Electrical Output | 0.900 | kW |
| Maximum Electrical Output | 2.80 | kW |

| Quantity | Value | Units |
|---|---|---|
| Fuel Consumption | 745 | L |
| Specific Fuel Consumption | 0.347 | L/kWh |
| Fuel Energy Input | 7,330 | kWh/yr |
| Mean Electrical Efficiency | 29.3 | % |

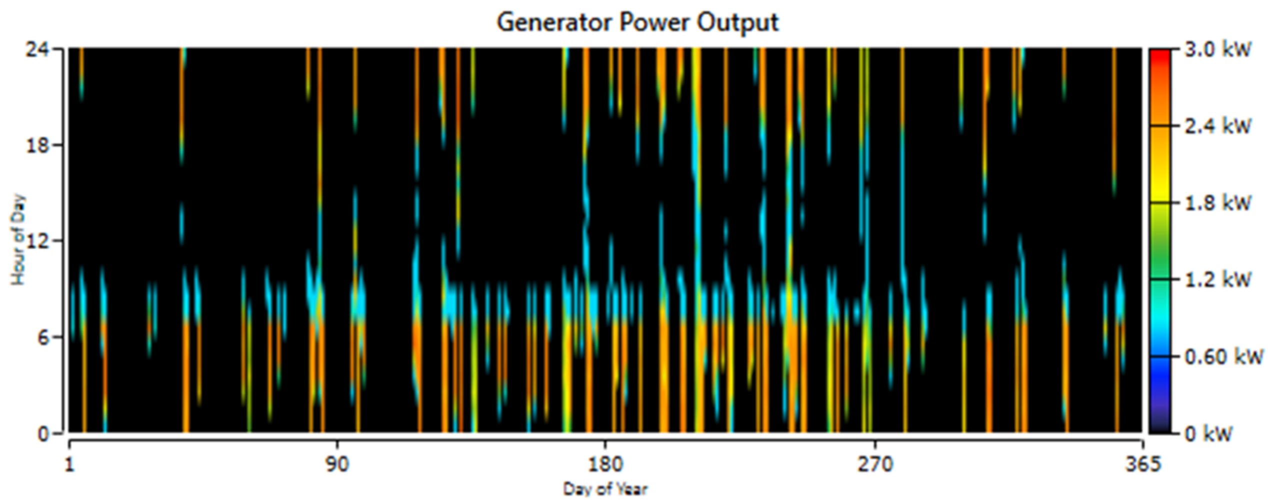



**Fig. 16: HOMER pro diesel generator summary for the system**

# Cost Summary of the System

Table 3: Optimal configuration for different systems

| | Size of components | | | | Economic Parameters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Configuration(S) | PV (kW) | WT (kW) | DG (kW) | Battery (Units) | Initial Cost ($) | O&M Cost ($) | NPC ($) | COE ($) | RF (%) | Diesel (L/yr.) | Gen Hr. (hr./yr.) |
| PV/Diesel/Battery | 15 | - | 3.6 | 24 | 27,480 | 1,723 | 44,343 | 0.223 | 89.4 | 745 | 1,181 |
| PV/Wind/Diesel /Battery | 14 | 1 | 3.6 | 24 | 33,280 | 1,813 | 51,029 | 0.256 | 88.3 | 828 | 1,324 |
| PV/Diesel | 5 | - | 3.6 | - | 7,880 | 5,884 | 65,473 | 0.329 | 22.7 | 5,475 | 8,760 |
| Diesel/Battery | - | - | 3.6 | 4 | 4,480 | 6,409 | 67,212 | 0.337 | 0 | 6,072 | 6,094 |
| Diesel only | - | - | 3.6 | - | 2,880 | 6,636 | 67,829 | 0.340 | 0 | 6,568 | 8,760 |

# Cost Summary & Environmental Impact

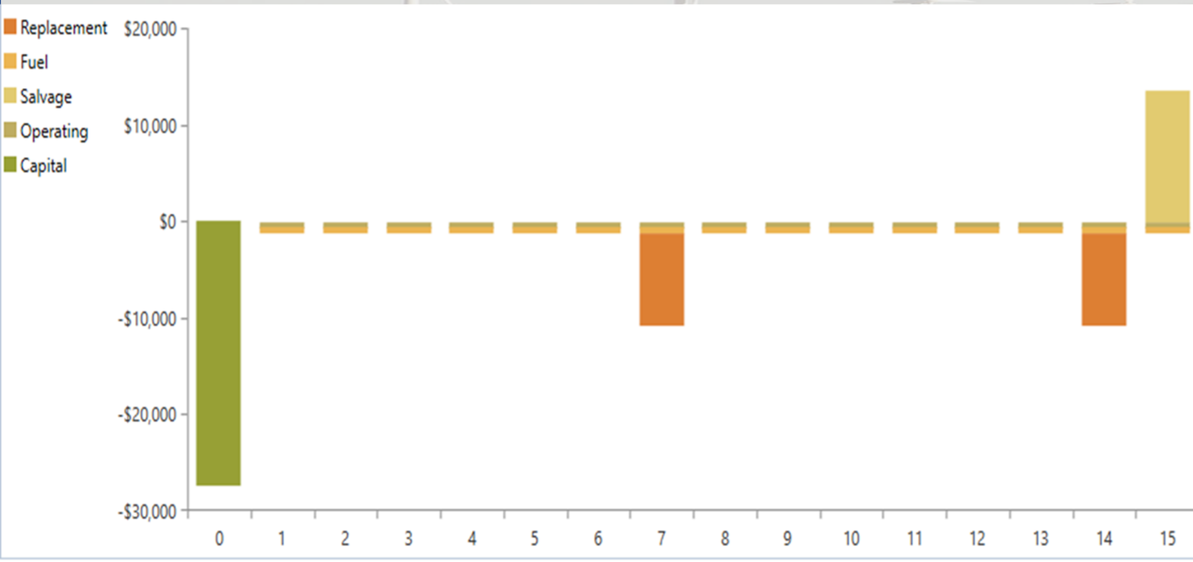



**Fig. 17: Cash flow of the Proposed system**

- 89.4% renewable penetration
- 75% cost reduction with less environmental impact.

**Table 4: Emissions comparison between the winning and base configuration**

| Emissions (kg/yr.) | PV/diesel/battery | Diesel |
|---|---|---|
| Carbon Dioxide ($CO_2$) | 1,950 | 17,192 |
| Carbon Monoxide (CO) | 12.3 | 108 |
| Unburned Hydrocarbons | 0.536 | 0.657 |
| Sulfur Dioxide ($SO_2$) | 4.78 | 42.1 |
| Nitrogen Oxides ($NO_X$) | 11.5 | 102 |

# Dynamic Modeling & Simulation

## Solar Photovoltaic

$$I = N_pI_{ph} - N_pI_{D1} - N_pI_{D2} - I_{sh} \quad (1)$$

$$I_{ph} = [I_{sc} + K_i(T - T_{ref})]G/1000 \quad (2)$$

$$I_{D1} = I_s\left[e^{\frac{q\left(\frac{V}{N_s}+\frac{IR_s}{N_p}\right)}{n1kT}-1}\right] \quad (3)$$

$$I_{D2} = I_s\left[e^{\frac{q\left(\frac{V}{N_s}+\frac{IR_s}{N_p}\right)}{n2kT}-1}\right] \quad (4)$$

$$I_{sh} = \frac{\frac{N_{pv}}{N_s}+IR_s}{R_{sh}} \quad (5)$$

$$I_s = I_{rs}\left(\frac{T}{T_{ref}}\right)^3 e^{\frac{qE_g\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)}{kn}} \quad (6)$$

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{qV_{oc}}{N_skT}-1\right)}} \quad (7)$$

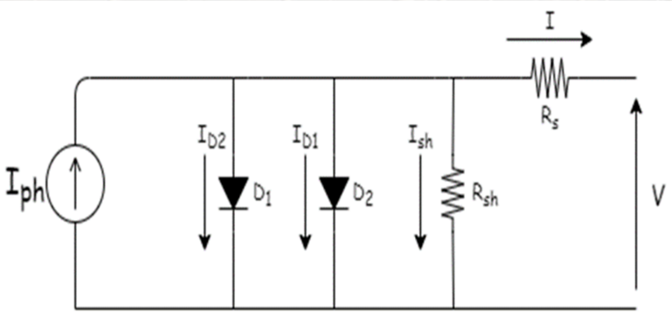



**Fig. 18: Two-diode solar PV equivalent circuit model**

2 diode model of PV cell offers:

- ❖ Better accuracy
- ❖ Better ideality factor

**Table 5: Photovoltaic modeling cell parameters**

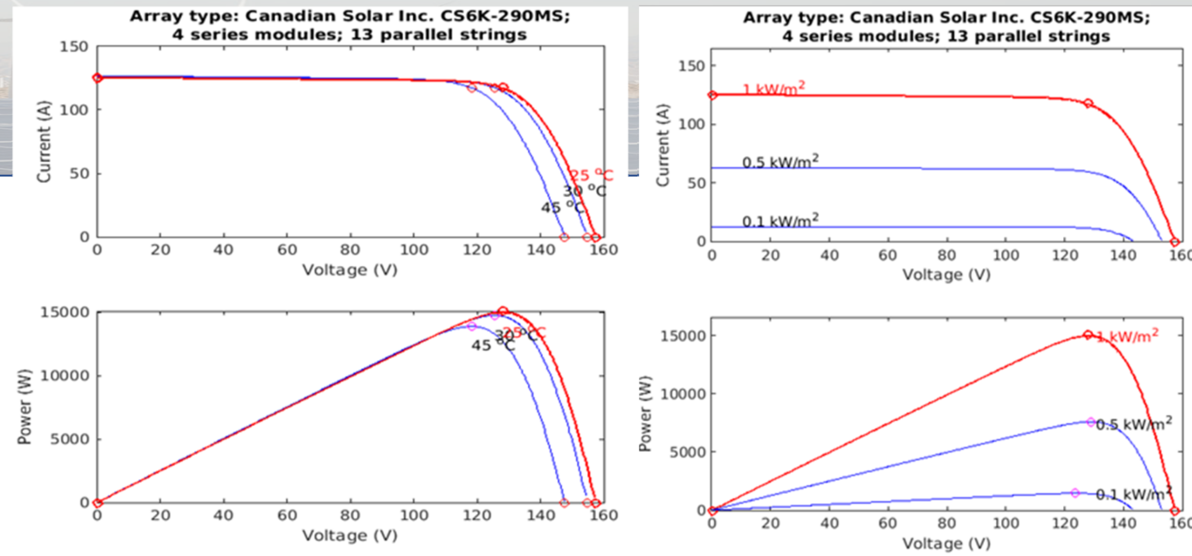
| Parameter | Description | Unit |
|---|---|---|
| $I_{ph}$ | Photocurrent | A |
| $G$ | Solar Irradiance | $W/m^2$ |
| $I$ | Output current | $A$ |
| $E_g$ | Band gap energy | 1.3 $eV$ |
| $I_{D1}$ | Current through diode 1 | A |
| $I_{D2}$ | Current through diode 2 | A |
| $R_s$ | Series resistance | Ω |
| $R_{sh}$ | Shunt resistance | Ω |
| $I_{rs}$ | Reverse Saturation current | A |
| $I_s$ | Shunt current | A |
| $I_{sc}$ | Short circuit current | A |
| $I_{sh}$ | Shunt current | A |
| **k** | Boltzmann constant | 1.38 $x$ $10^{-23}$ $J/K$ |
| $K_i$ | Temperature coefficient of current | A/°C |
| $n_1$ | Ideality factor of diode 1 | 1 |
| $n_2$ | Ideality factor of diode 2 | 1 |
| **q** | Electron charge | 1.6 $x$ $10^{-19}$ $C$ |
| **T** | Temperature of Solar cell | °C |
| $T_{ref}$ | Temperature reference of cell | °C |
| $V_{oc}$ | Open circuit Voltage | V |
| $N_p$ | Number of parallel connected cell | N |
| $N_s$ | Number of series connected cell | N |

# Dynamic Modeling & Simulation

## Solar Photovoltaic

**Table 6: Technical Specification of the selected Solar Panel**

| Model Number | CS6K-290MS |
|---|---|
| Nominal Maximum Power ($P_{Max}$) | 290 Watts |
| Optimum Operating Voltage (Vmp) | 32.10 Volts |
| Optimum Operating Current (Imp) | 9.05 Amps |
| Open Circuit Voltage (Voc) | 39.30 Volts |
| Short Circuit Current (Isc) | 9.67 Amps |
| Module Efficiency | 17.72% |
| Maximum System Voltage | 1000 V (IEC) |
| Temperature Coefficient (Pmax) | -0.39 % / °C |
| Temperature Coefficient (Voc) | -0.30 % / °C |
| Temperature Coefficient (Isc) | 0.053 % / °C |
| Nominal Operating Cell Temperature | 45 ± 2 °C |
| Manufacturer | Canadian Solar |




**(a) Varying temperature** **(b) Varying Irradiance**

**Fig. 19: I-V and P-V curves for varying temperature and irradiance**

- ❖ PV array size of 15 kW
- ❖ 4 panels in series and 13 panels in parallel

# Dynamic Modeling & Simulation

## Maximum Power Point Tracking (MPPT)

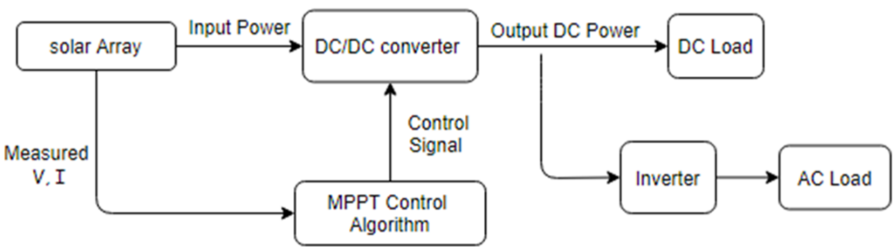



Fig. 20: MPPT schematic block.

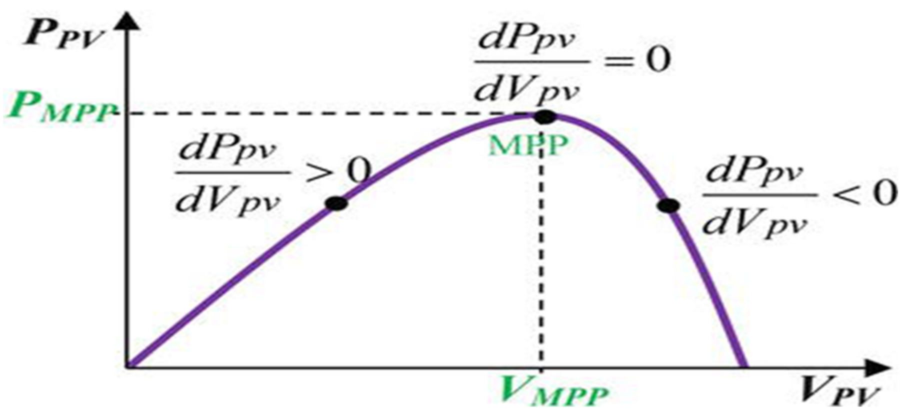



Fig. 21: Incremental conductance characteristic

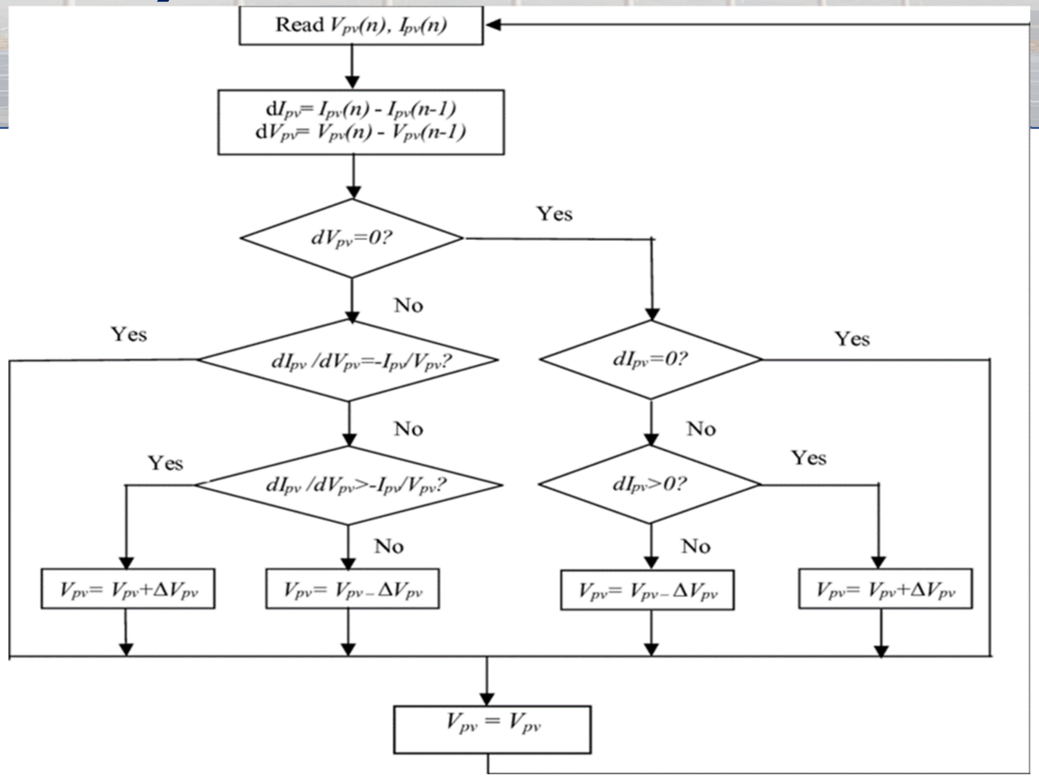



Fig. 22: Incremental Conductance algorithm flowchart

# Dynamic Modeling & Simulation

## DC-DC Converter

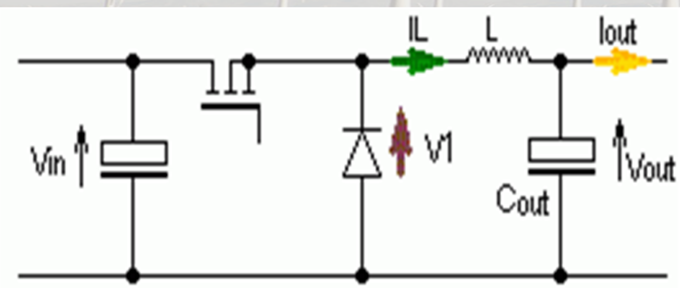



**Fig. 23: Buck Converter Circuit.**

$$V_{out} = V_{in} * D \quad (8)$$

$$L_{min} = \frac{(1-D)R}{2f} \quad (9)$$

- $L_{min}$, minimum inductance required for continuous operation
- $D$ is the duty cycle calculated at minimum input voltage
- $R$ is the maximum load resistance
- $f$ is the switching frequency

**Table 7: Buck Converter Design parameters**

| | | | |
|---|---|---|---|
| **Input** | $V_{in\_min}$ = 48.0V | $V_{in\_max}$ = 128.0V | $V_{in}$ = 128.0V |
| | $V_{out}$ = 48.0V | $I_{out}$ = 314.17A | f = 5.0kHz |
| **Result** | L = 53.60uH | $\Delta I_L$ for $V_{in\_max}$ = 125.67A | |

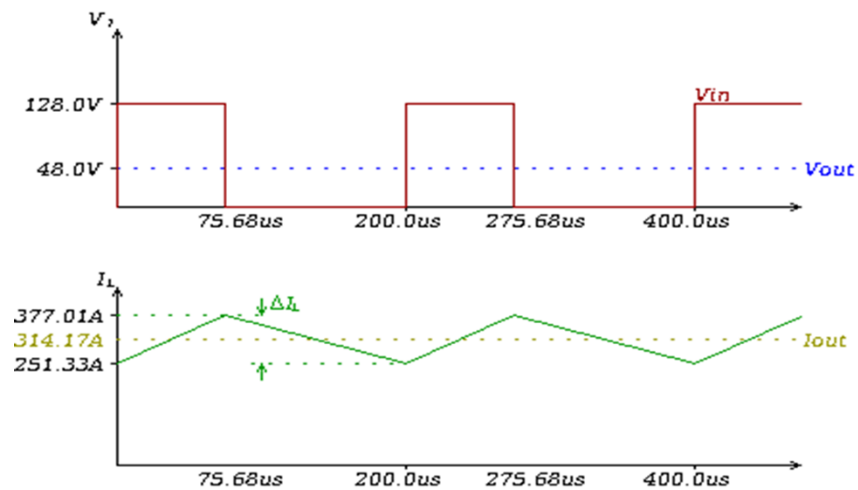



**Fig. 24: Output Voltage and Current responses of the Buck Converter at MPP Voltage**

# Dynamic Modeling & Simulation

## Battery Storage System

The charging, discharging and the SOC of the battery can be modeled as follows

$$E_{charge} = E_0 - \frac{KQi^*}{i_t + 0.1Q} - \frac{KQi_t}{Q - i_t} + Laplace^{-1}\left(\frac{A}{{}^{s}/_{Bi_t} + 1} \cdot \frac{1}{s}\right) \quad (10)$$

$$E_{discharge} = E_0 - \frac{KQi^*}{Q - i_t} - \frac{KQi_t}{Q - i_t} + Laplace^{-1}\left(\frac{A}{{}^{s}/_{Bi_t} + 1} \cdot 0\right) \quad (11)$$

$$SOC = 100 * \left(1 + \frac{\int i_t dt}{Q}\right) \quad (12)$$

Where $E_0$ is constant voltage $V$, $Q$ is the maximum battery capacity in $Ah$, $K$ is the polarization constant in $Ah^{-1}$, $i_t$ is extracted battery capacity $Ah$, $i^*$ is the low frequency current dynamics in $A$, $B$ is exponential capacity $(Ah)^{-1}$ and $A$ is the exponential voltage in $V$

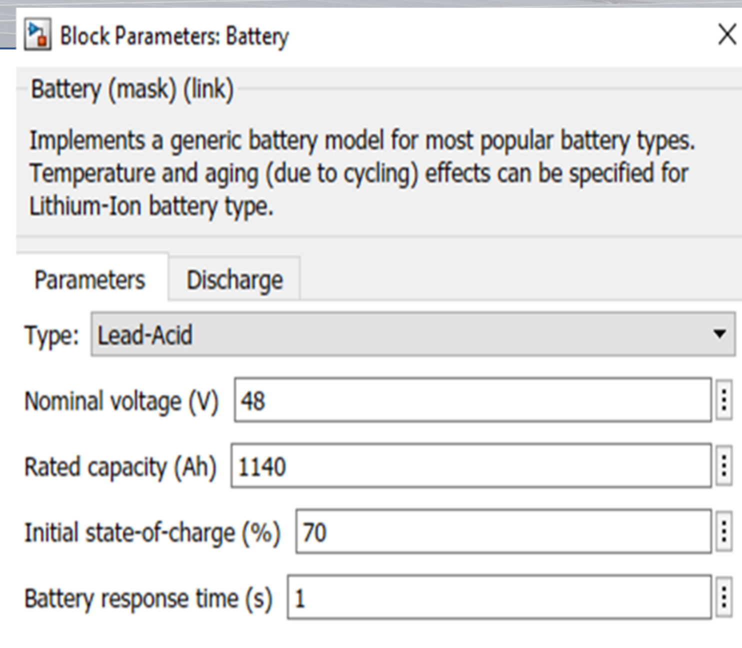
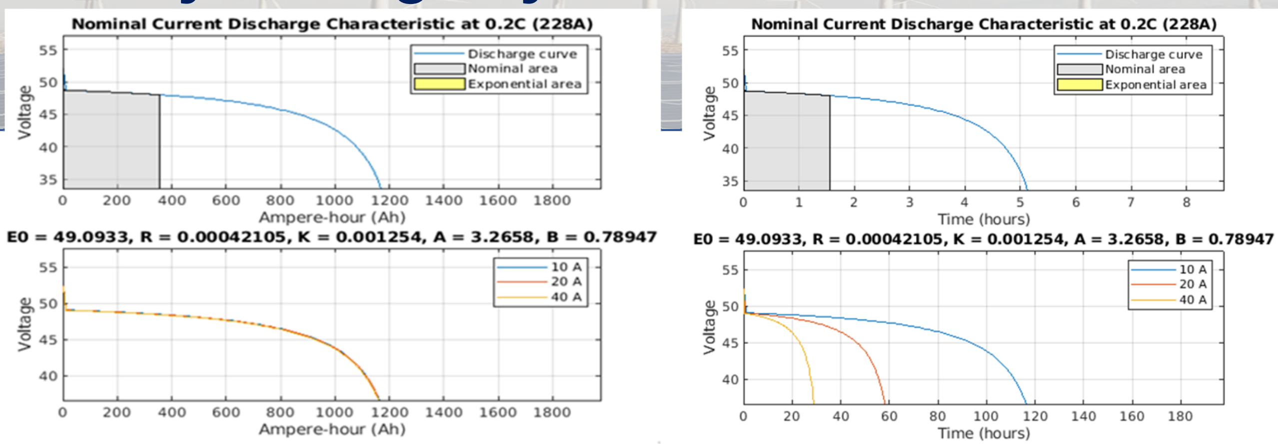



Fig. 25: Battery initial parameters for simulation

# Dynamic Modeling & Simulation

## Battery Storage System




**(a) Capacity characteristics** **(b) Time Characteristics**

**Fig. 26: Battery discharge characteristics**

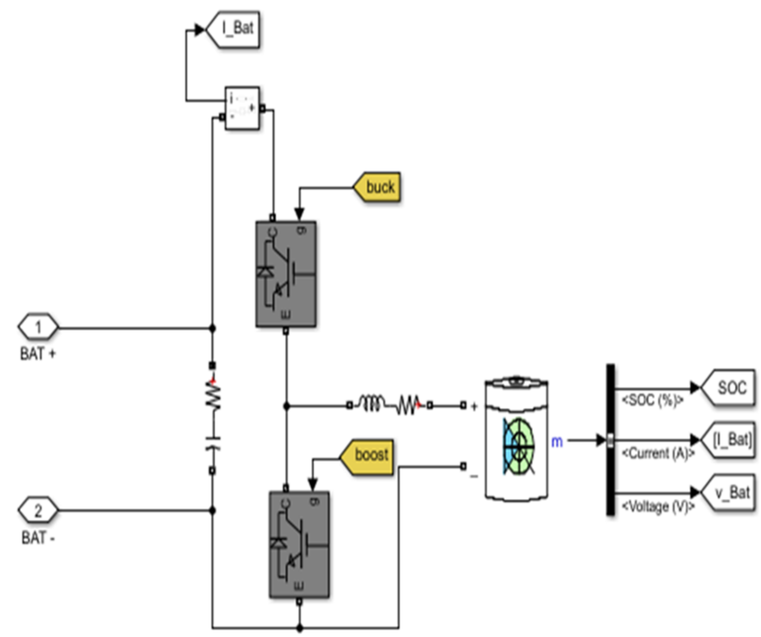



**Fig. 27: Model of battery subsystem in Simulink**

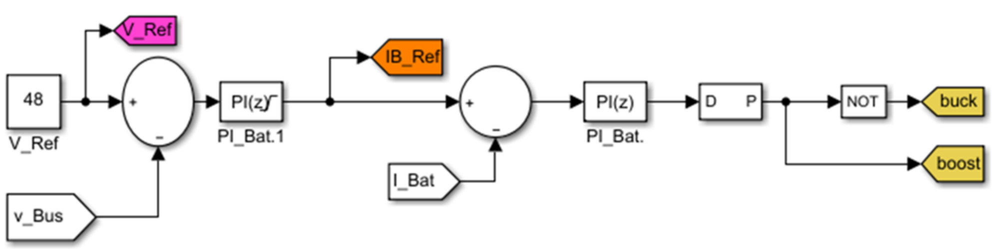



**Fig. 28: Charge controller topology for the Battery**

# Dynamic Modeling & Simulation

## Diesel Generator System : PMSG

$$\frac{di_d}{dt} = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_m \quad (13)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q + \frac{L_d}{L_q}p\omega_m i_d - \frac{\lambda p\omega_m}{L_q} \quad (14)$$

$$T_e = \frac{3}{2}p\left[\lambda i_q + (L_d - L_q)i_d i_q\right] \quad (15)$$

**Table 8: PMSG Parameters**

| | |
|---|---|
| $L_q$, $L_d$ | q-axis and d-axis inductances of the generator (H) |
| R | Resistance of the stator windings (Ω) |
| $i_q$, $i_d$ | q-axis and d-axis currents (A) |
| $v_q$, $v_d$ | q-axis and d-axis voltages (V) |
| $\omega_m$ | Angular velocity of the rotor (rad/s) |
| λ | Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases |
| p | Number of pole pairs |
| $T_e$ | Electromagnetic torque (N.m) |

# Dynamic Modeling & Simulation

## Diesel Generator System: Simulink

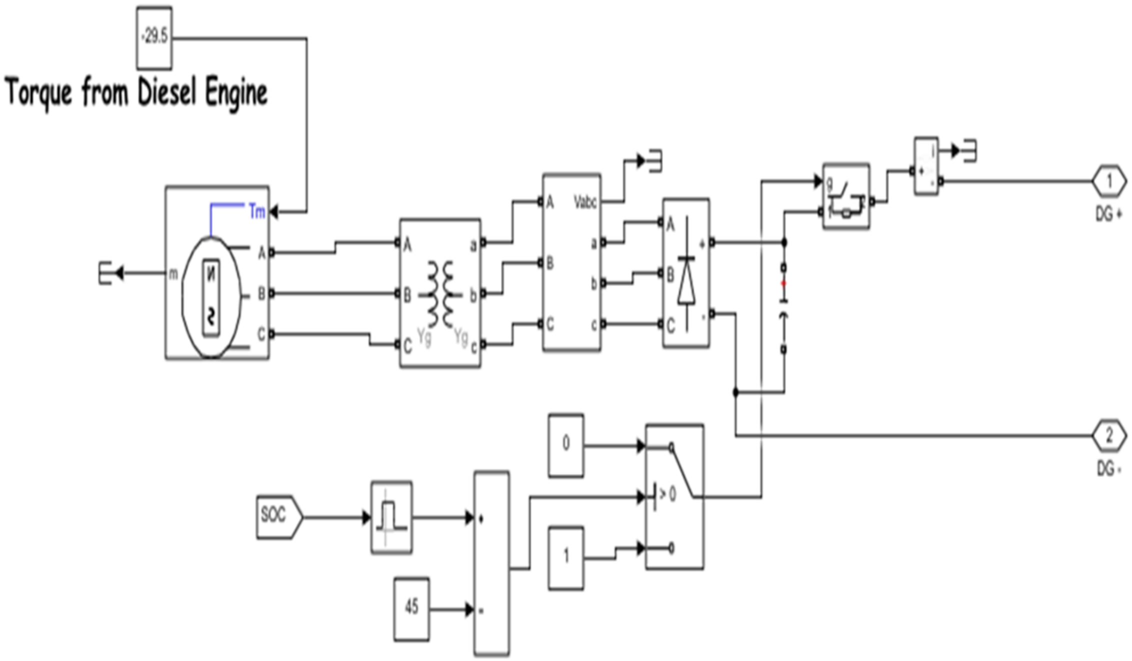



Fig. 29: Diesel Generator and Rectifier System

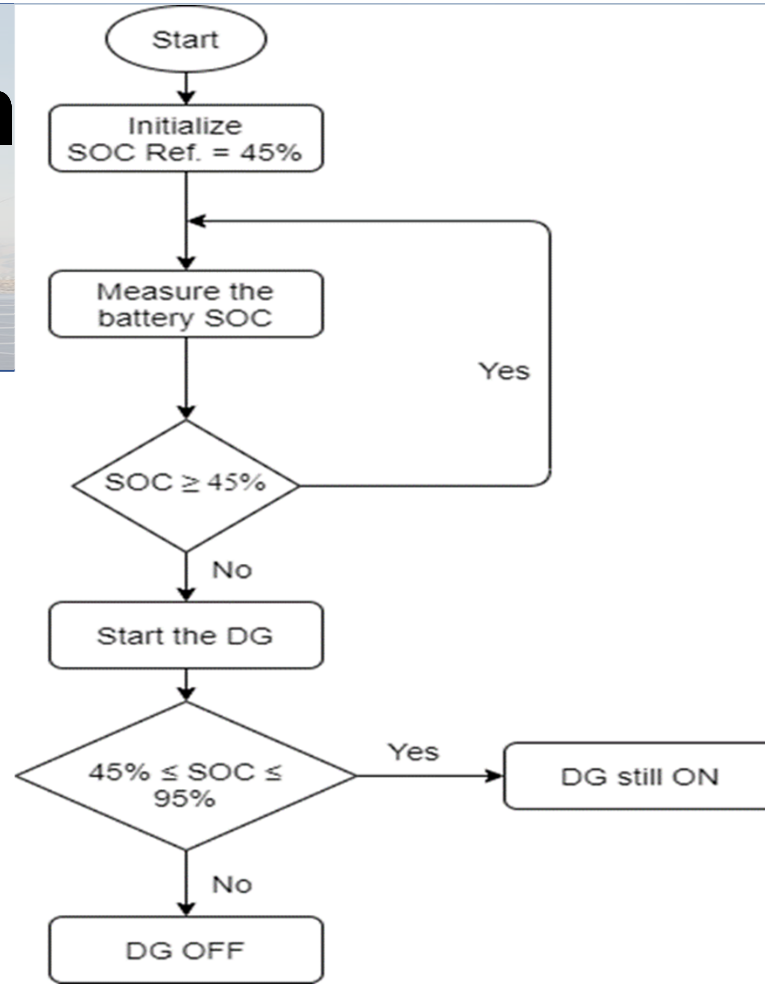
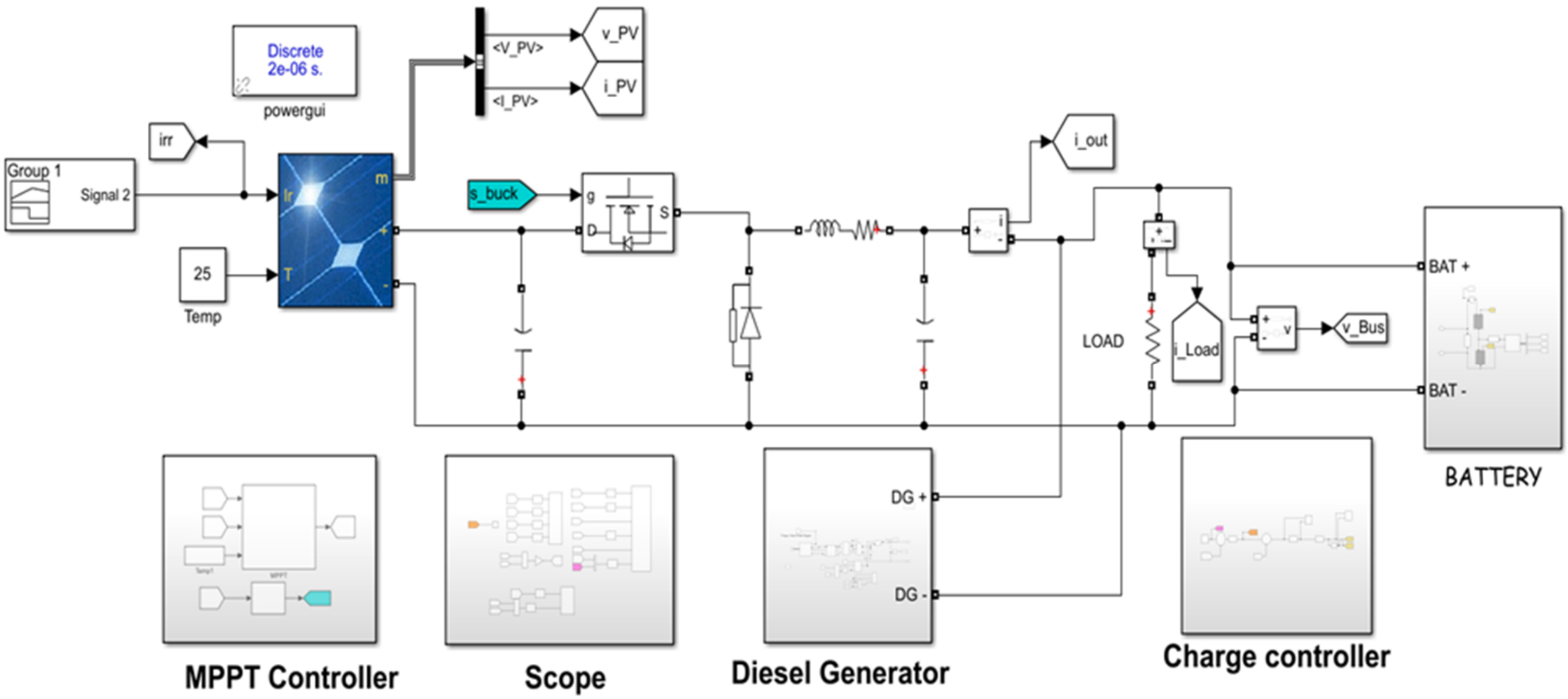



Fig. 30: Generator Control logic

# Dynamic Modeling & Simulation

## Simulink Model




Simulated at Peak load of 3.2 kW @ 48 V bus, Load resistor value, 0.72Ω

Fig. 31: Model of the hybrid system in Simulink

# Dynamic Modeling & Simulation

## Results

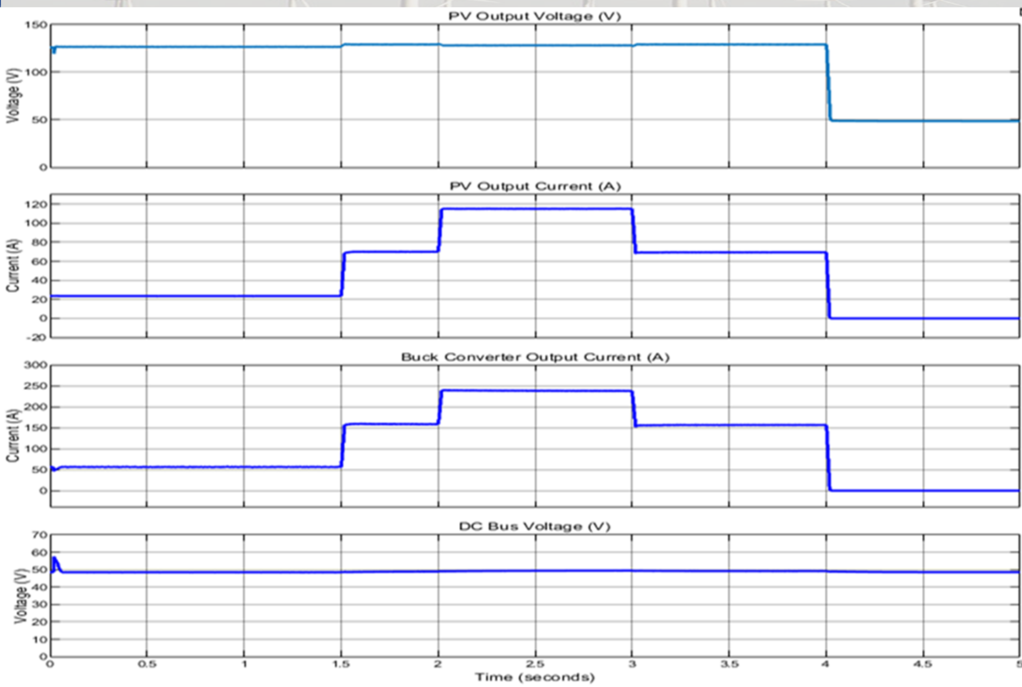
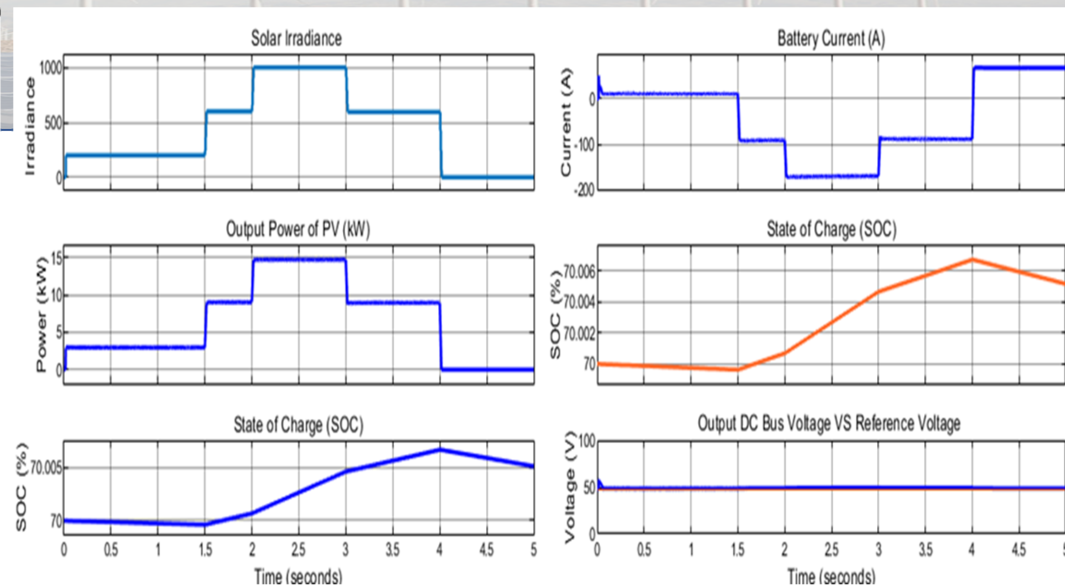



**Fig. 32: PV voltage, Current, buck converter current and DC bus voltage**




**(a) Solar Irradiance, PV output power & SOC of battery**

**(b) Battery current, SOC & DC bus voltage**

**Fig. 33: Solar Irradiance, PV output power SOC of battery, current, DC bus voltage**

# Dynamic Modeling & Simulation

## Results

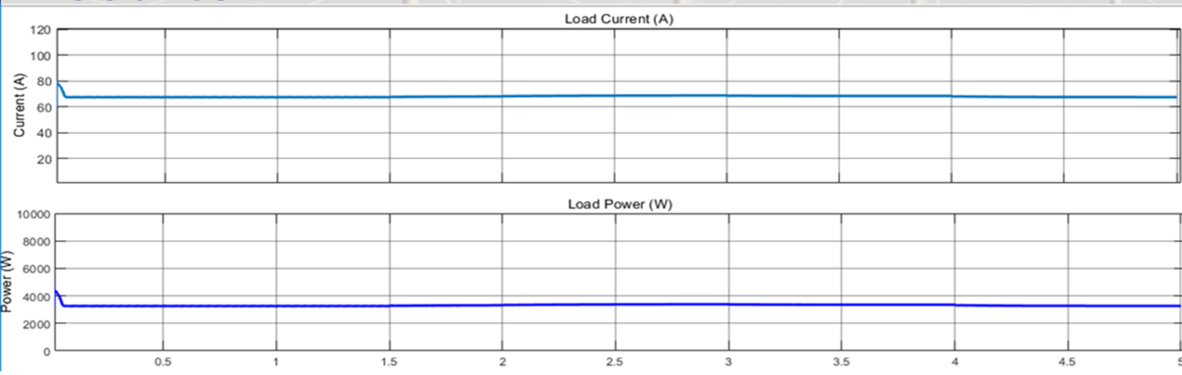



**Fig. 34: Load current and load power**

The current drawn by the load is constant at 66.7 A at a bus voltage of 48 V.

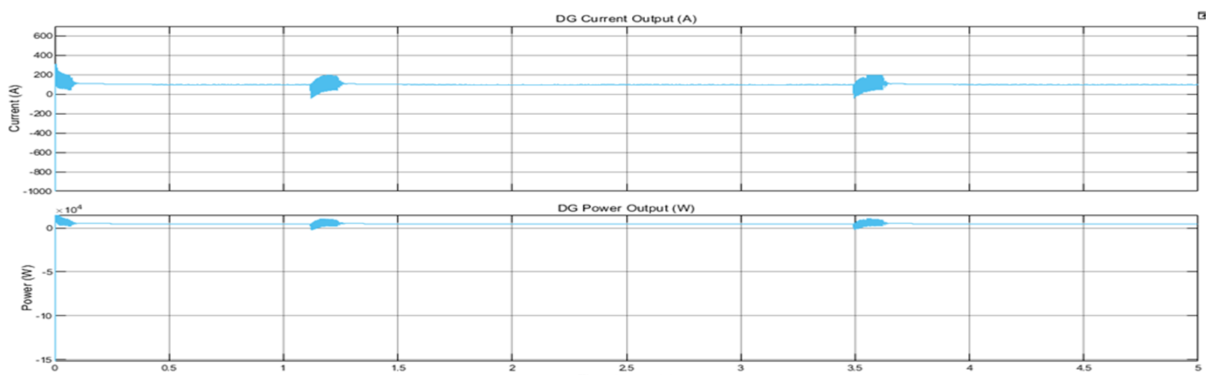



**Fig. 35: Rectified diesel generator output current and power**

# Dynamic Modeling & Simulation

## Results

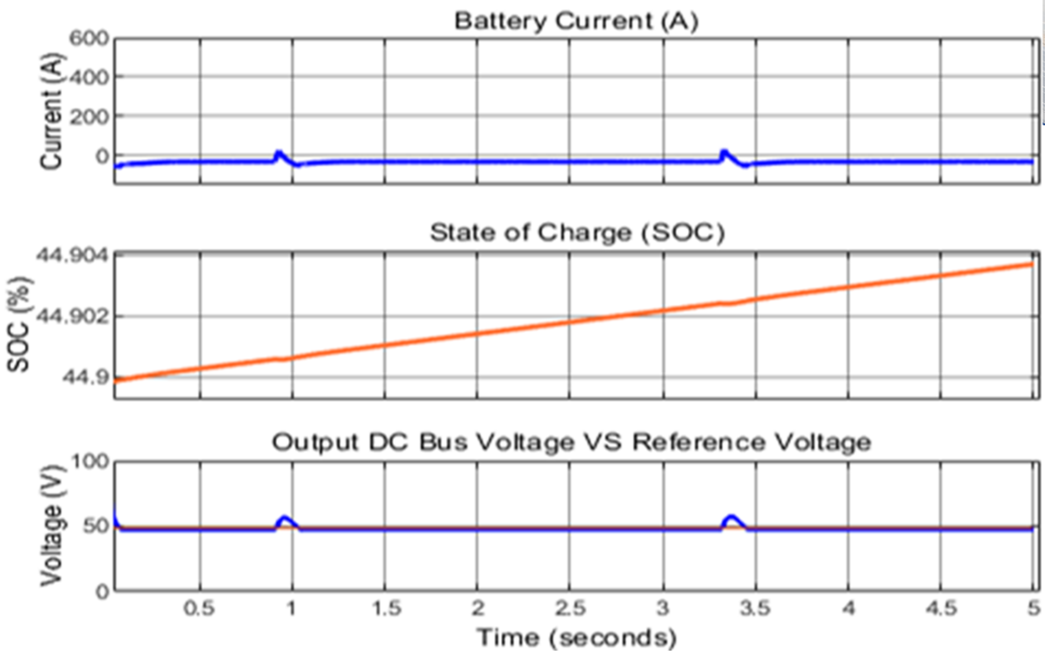



**Fig. 36: Battery charging current, SOC and output DC voltage due to diesel generator**

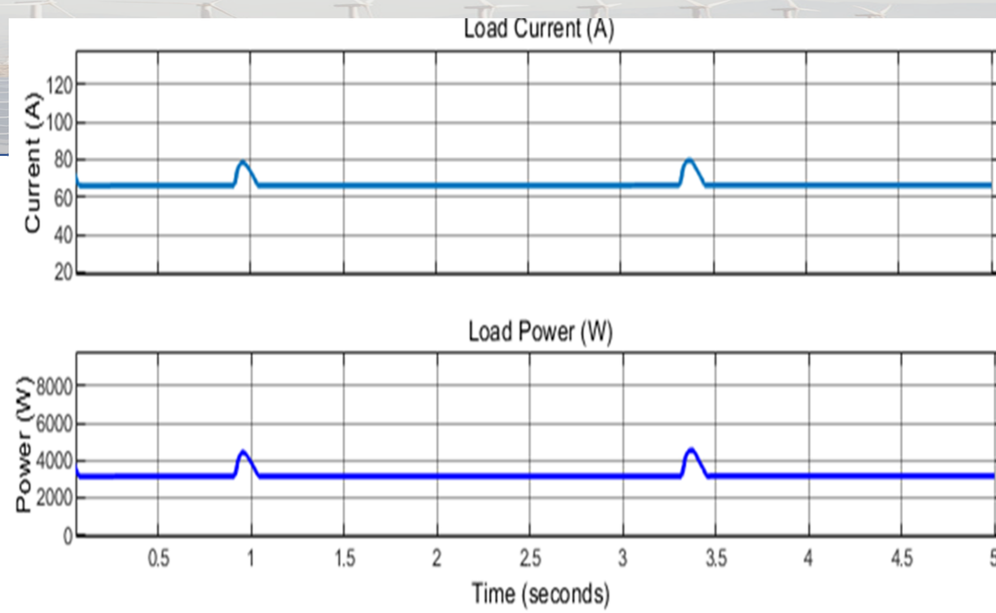



**Fig. 37: Output current and power due to diesel generator**

Negative battery current indicates charging

The current absorbed by the load is 66.7 A same as PV

# Low-Cost Open Source SCADA system Design

## Motivation

- ❖ Remoteness of Base Transceiver Stations
- ❖ Critical Nature of Operations
- ❖ High Cost of Proprietary SCADA System

## Objective:

To Design an open-source, Low-cost SCADA system to monitor and control a remote base transceiver station.

# Low-Cost Open Source SCADA system Design

## Base Transceiver Station Design Overview

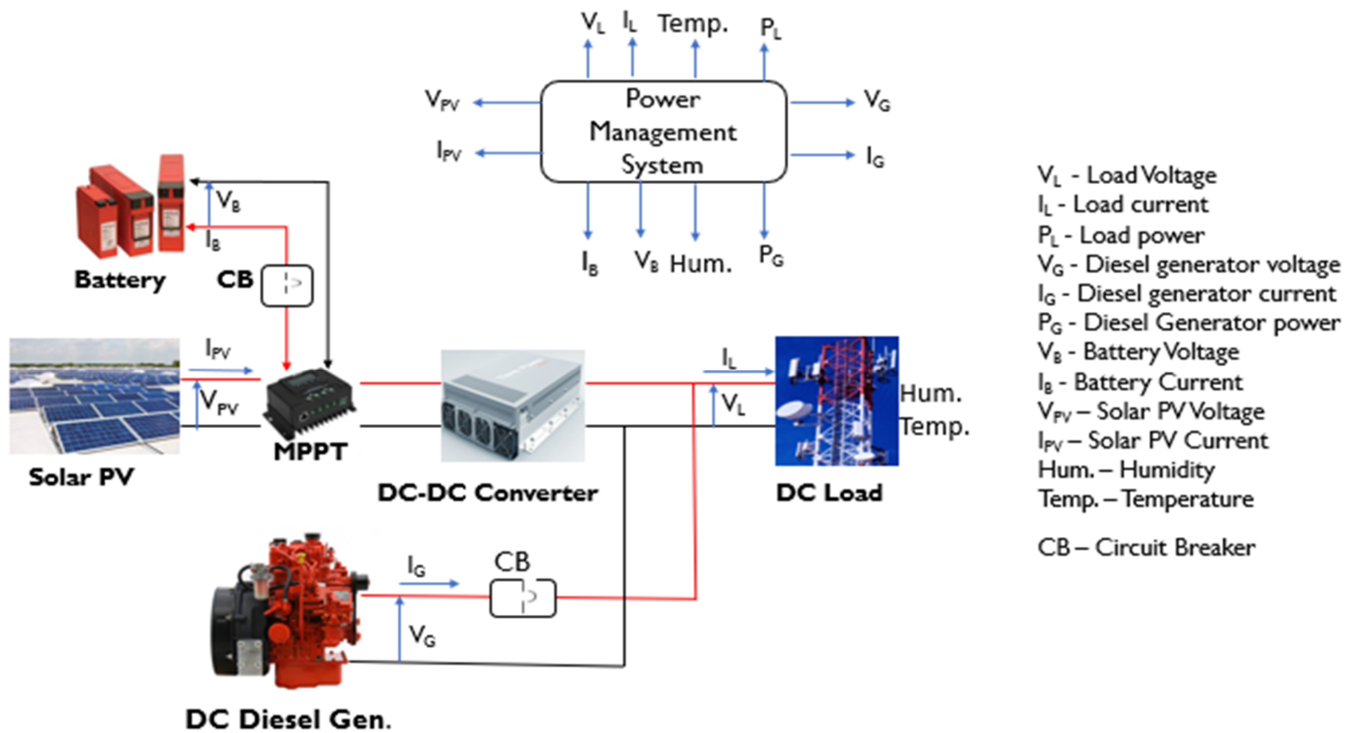



Fig. 38: Hybrid power system

# IoT-based SCADA

***Supervise*** → **Field Instrument Devices (FIDs)**

**Sensors and Actuators connected to the system**

***Control*** → **Remote Terminal Devices (RTUs)**

**Microprocessor based device that monitors and controls field devices**

**&**

**Data** → **Communication Network**

**Connect the remote terminal units (RTUs) with the SCADA Master (MTU)**

**Acquisition** → **Master Terminal Unit (MTU)**

**Issues the Control commands to the Remote Terminal Unit (RTUs), Gathers, store, process and display Data**

# Schematic of the Proposed System

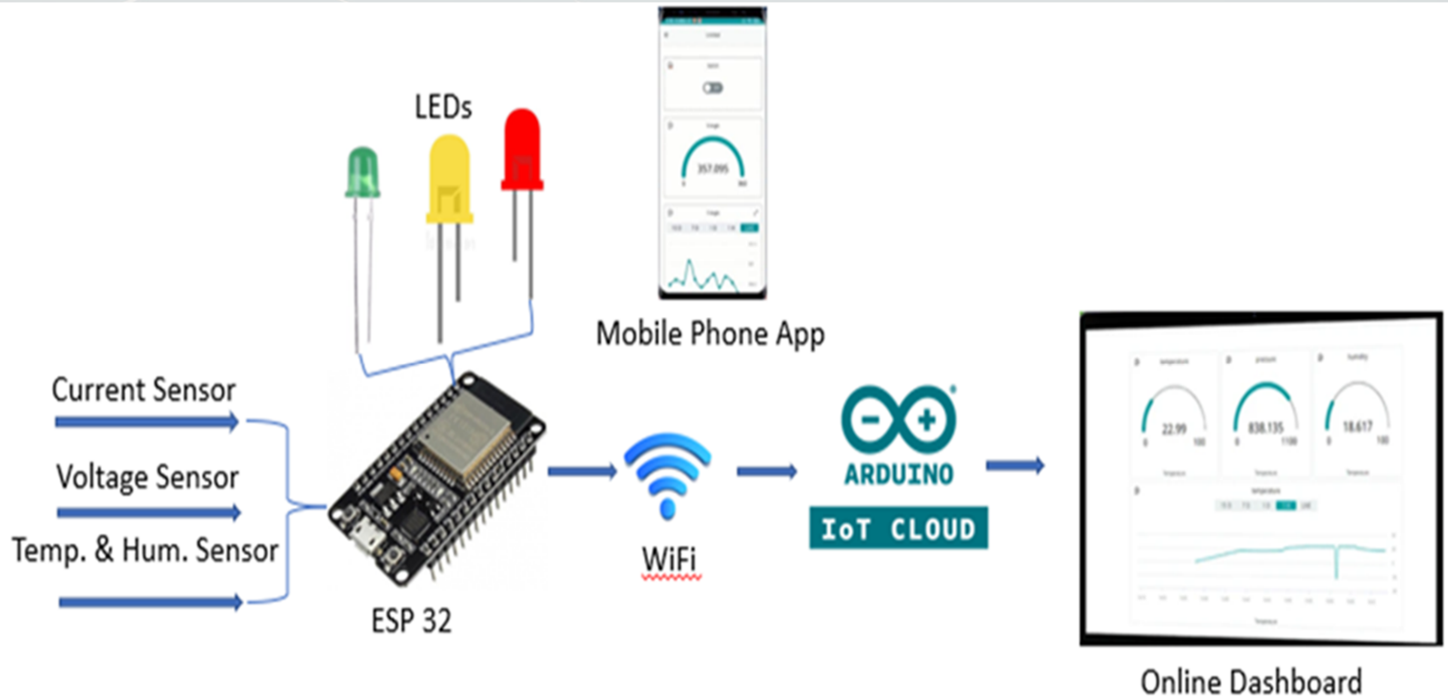



Fig. 39: Schematic of the Proposed IoT SCADA system

# Components Description of the Proposed System

## ESP32 – WROOM – 32 Module (RTU)

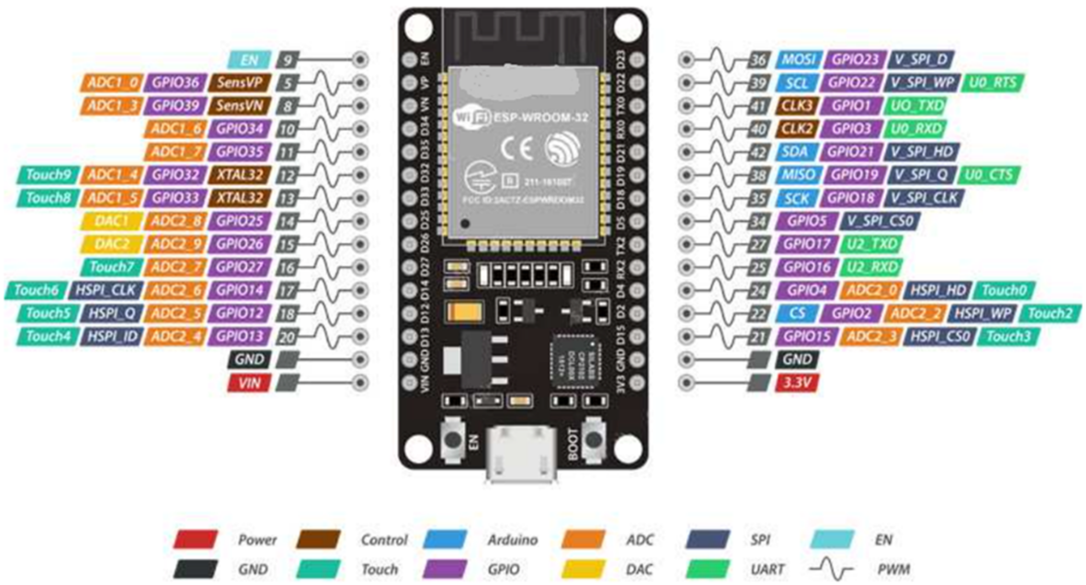



Fig. 40: Pinout configuration of ESP32-WROOM-32 microcontroller

- ESP32-WROOM-32 contains two low-power Xtensa 32-bit LX6 microprocessors.
- 448 KB ROM for booting and core functions.
- 520 KB on-chip SRAM
- Wi-Fi: 802.11 b/g/n up to 150 Mbps
- Security WPA/WPA2/WPA2-Enterprise/WPS
- IPv4, IPv6, SSL, TCP/UDP/HTTP/FTP/MQTT
- Operating voltage: 3.3 V
- Input voltage: 7 – 12 V

# Components Description of the Proposed System

## Field Instrument Devices (FIDs)

### Temperature and Humidity Sensor

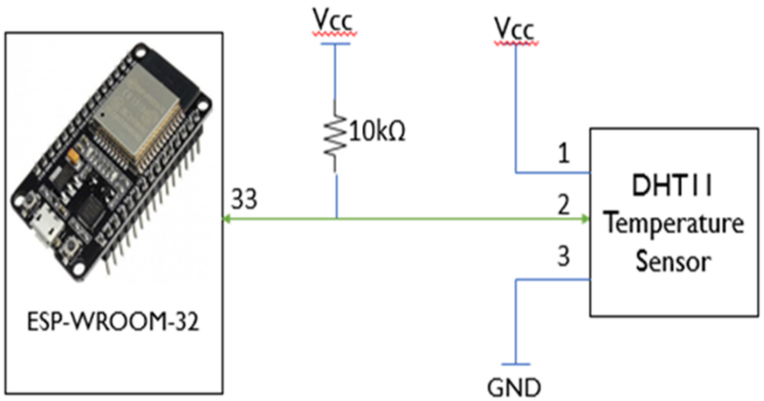



Fig. 41: Connection between ESP32 and DHT11

- ❖ Temperature range - 0°C to 50°C
- ❖ Humidity range – 20% to 90%
- ❖ Precision 1°C, 1%
- ❖ Operating voltage 3 -5.5V

### Voltage Sensor Module

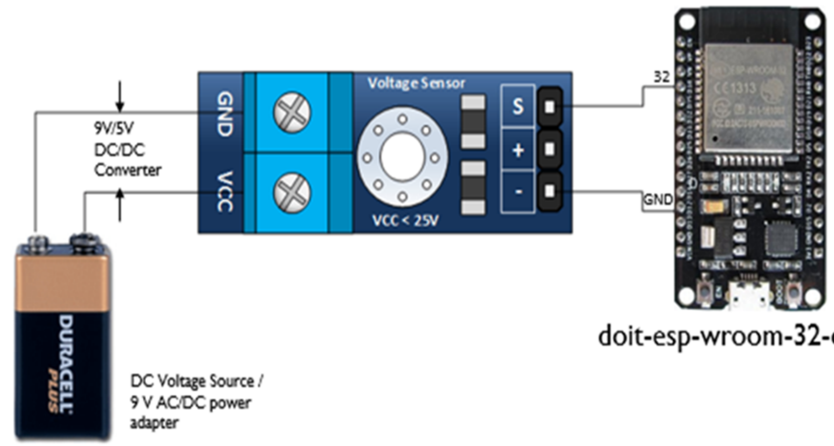



Fig. 42: Interfacing diagram of the voltage sensor with ESP32

- ❖ Voltage divider principle
- ❖ Operating voltage 3.3 – 5.0 V
- ❖ Range 0 – 25 V DC.
- ❖ Connected in parallel

# Components Description of the Proposed System

## ACS 712 Hall-Effect Current Sensor

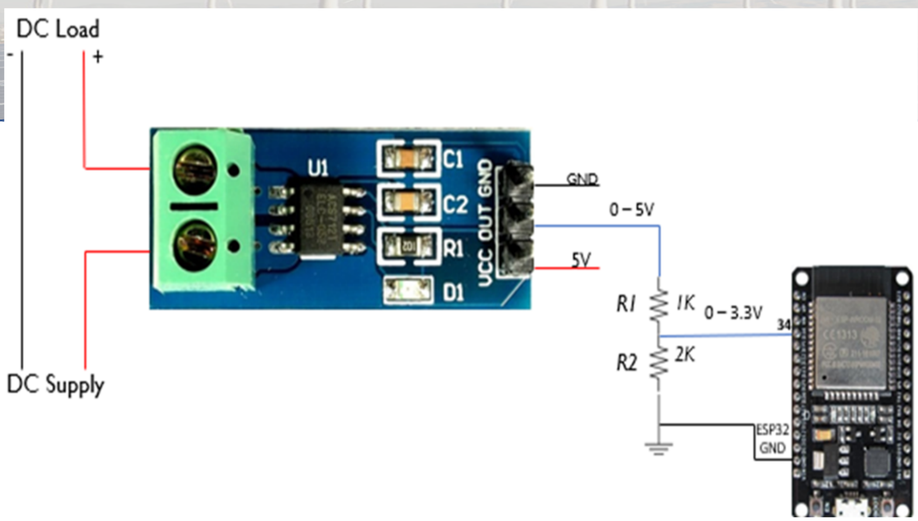



**Fig. 43: ACS712 connection to ESP32 microcontroller**

- ❖ Works on the principle of Hall-Effect
- ❖ 5 VDC to power it
- ❖ ADC pins operate between 0 - 3.3 V

$$V_{ESP} = \frac{R_2}{R_1 + R_2} \times V_{CC} \quad (16)$$

$V_{ESP}$ is the ESP32 voltage and $V_{CC}$ is the sensor input voltage.

## Wi-Fi Router (Communication Link)

- ❖ Actiontec R3000 FibreOP router
- ❖ Data transfer rate 1 Gbps over ethernet,
- ❖ 2.3 Gbps over Wi-Fi

# Arduino IoT Cloud Platform

- ❖ Creating Arduino IoT Cloud Account and Cloud Plan
- ❖ Creating a "Thing"
- ❖ Connecting Devices to a Network
- ❖ Creating and Declaring Cloud Variables
- ❖ Creating Sketches and Dashboard
- ❖ Installing Arduino Create Agent

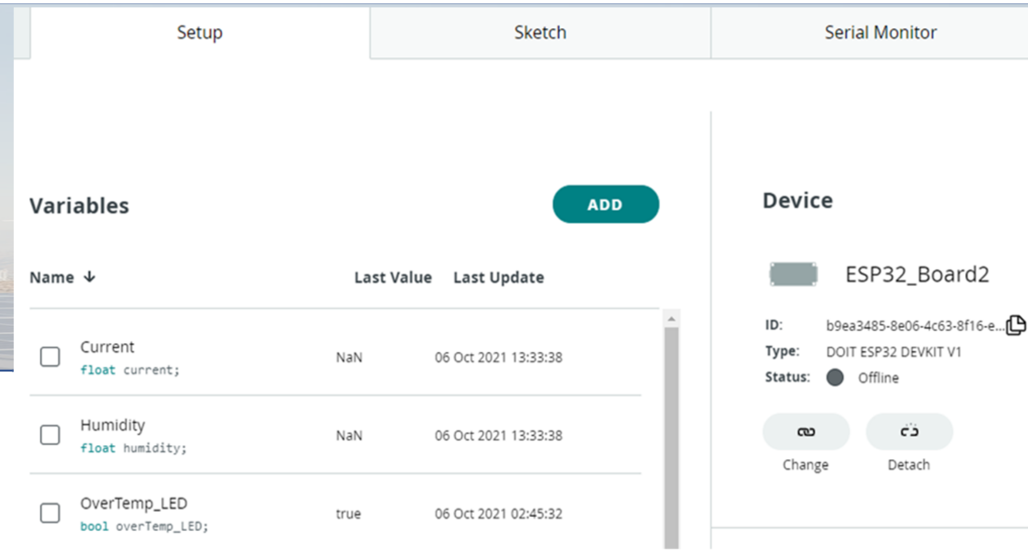



Fig. 44 :Declared variables and device on Arduino IoT Cloud

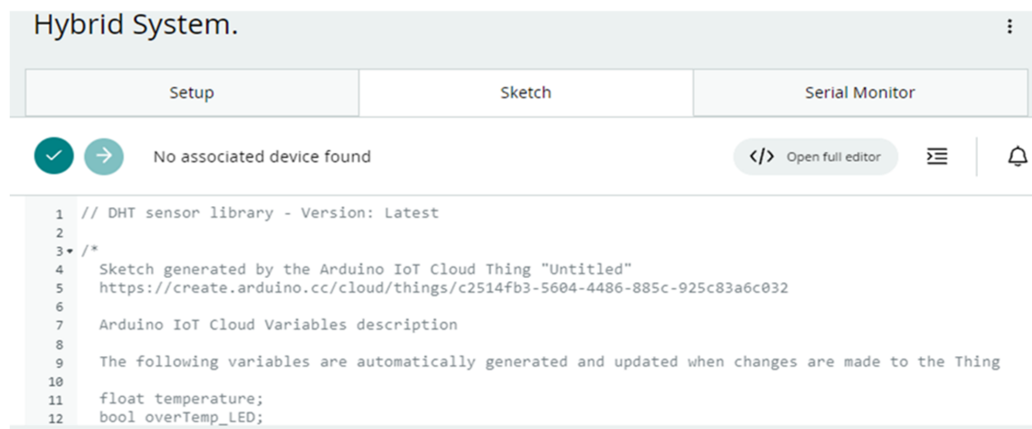



Fig. 45: Web editor on Arduino IoT Cloud

# Hardware Design

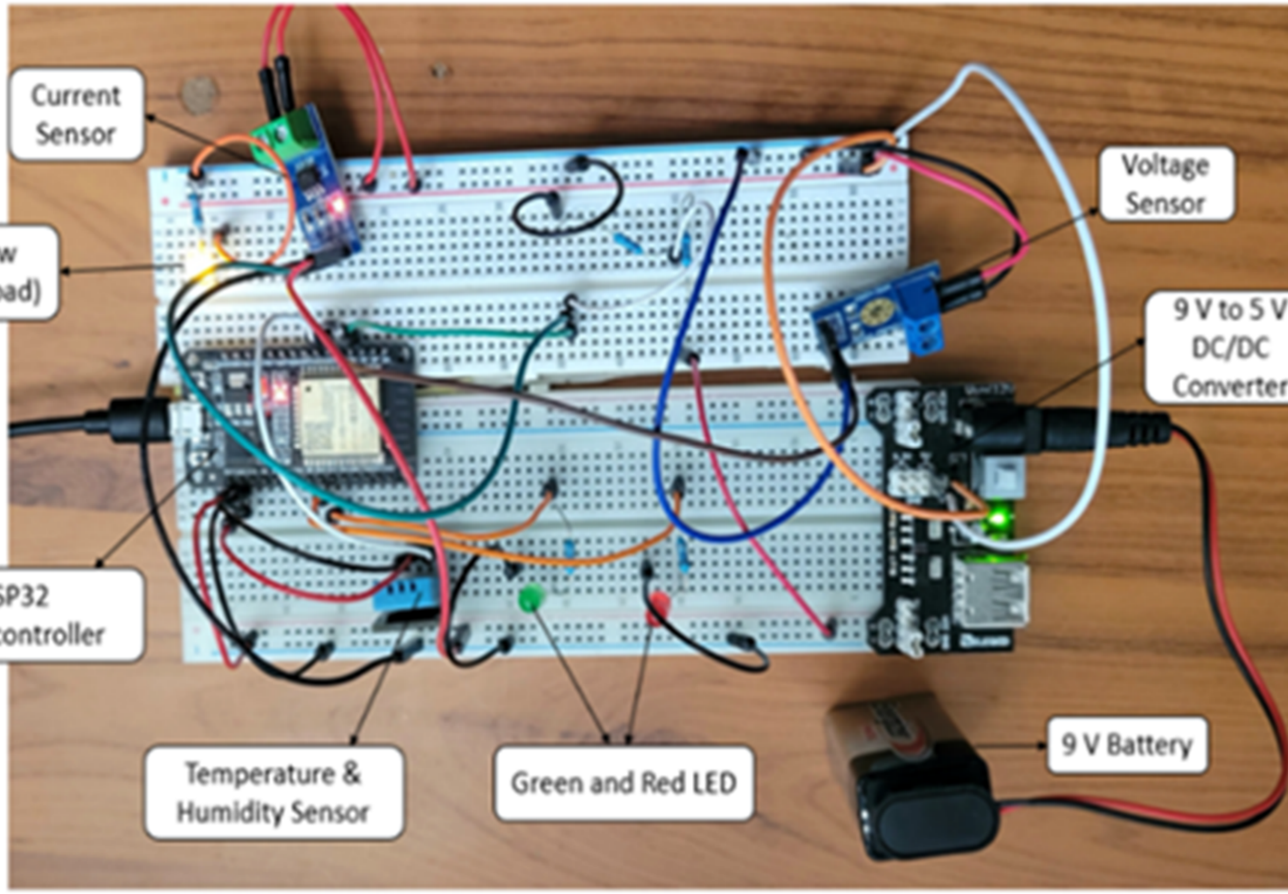



Fig. 46: Experimental circuit setup for the IoT SCADA system prototype

# Hardware Design

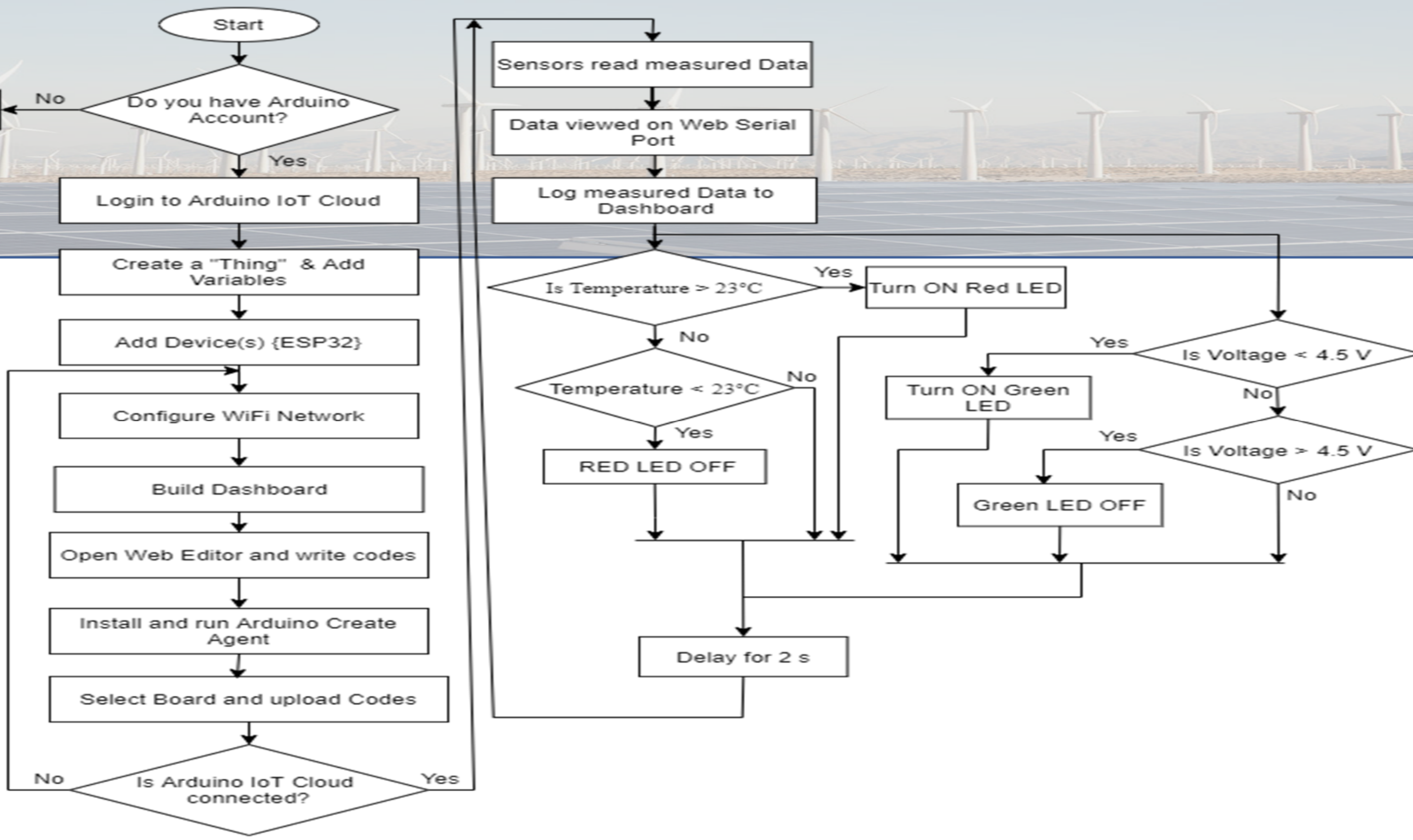



Fig. 47: Flowchart of the IoT SCADA system solution

# Results

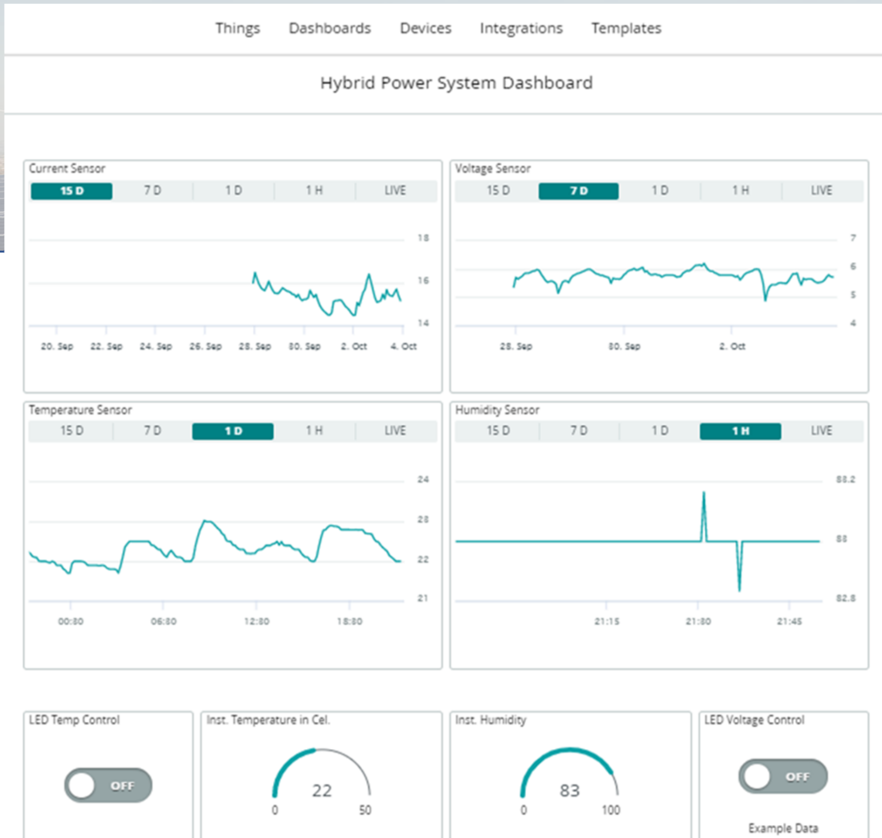



Fig. 48: Dashboard showing the measured parameters


Fig. 49: Temperature control of the system

# Results

**The SCADA system has the following features:**

- ❖ IoT based
- ❖ Low cost, low power, and open-source
- ❖ Supervisory Control

**Table 9: List of components and cost**

| S/N | Component(s) | Quantity | Price (USD) |
|---|---|---|---|
| 1 | ESP32 WROOM-32 | 1 | 13.85 |
| 2 | 9 V AC/DC power adapter | 1 | 10.34 |
| 3 | Breadboard Power Module | 1 | 6.40 |
| 4 | Current Sensor | 1 | 4.76 |
| 5 | Voltage Sensor | 1 | 4.80 |
| 6 | Temperature/Humidity Sensor | 1 | 5.20 |
| 7 | Arduino IoT Cloud plan (Entry) per month | N/A | 2.99 |
| 8 | Miscellaneous (Resistors, Breadboard, LEDs, wires, USB) | N/A | 40.00 |
| | **Total** | | **88.34 USD** |


**Fig. 50: Mobile App**

# Summary and Conclusions

The research contributions of this study can be broadly summarized as follows:

- ❖ Accurate sizing of the hybrid system based on actual field data to power a BTS site
- ❖ Cost comparison between existing system and the proposed hybrid system
- ❖ Comparison of the environmental impact of the designed system to the existing one
- ❖ Dynamic modeling and simulation of the system to study the transient behaviour
- ❖ Implementing a low-cost IoT-based SCADA system for the designed hybrid system.

# Recommendations for future studies

- This study was done based on actual load data measurement from the site. Having this implemented on the site to study the actual dynamics of the system will be a priority.
- The backup battery can be upgraded from the lead-acid battery to a lithium-ion battery to improve the discharge rate for which lead-acid ideally cannot be discharged above 0.1C.
- Designing a solar/wind/diesel/fuel cell system with a more renewable penetration for the site
- Carry out similar studies for other locations and compare all the parameters to conclude what can be adopted as the standard for a rural telecommunication site in Nigeria.
- Accurately compare the carbon emission of this studied system with the current one on site.
- Incorporate Email and text messages to the IoT platform when any supervisory control is carried out anywhere in the world.
- Investigate the integration of low power systems like LoRa to replace the Wi-Fi used as a communication channel for the IoT SCADA.

# List of Publications

1. C. Oton and M. T. Iqbal, "Design and Analysis of a Stand-alone DC Hybrid Microgrid for a Rural Base Transceiver Station in Nigeria," *2020 IEEE Electric Power and Energy Conference (EPEC), 2020,* pp. 1-6, doi: 10.1109/EPEC48502.2020.9320006.

2. Oton, C. and Tariq Iqbal, M., "Dynamic Modeling and Simulation of a Stand-alone DC Hybrid Microgrid for a Base Transceiver Station in Nigeria," *European Journal of Electrical Engineering and Computer Science. 5, 2 (Apr. 2021)*, 41-49. DOI:https://doi.org/10.24018/ejece.2021.5.2.316.

3. C. N. Oton and M. T. Iqbal, "Low-Cost Open Source IoT-Based SCADA System for a BTS Site UsingESP32 and Arduino IoT Cloud," *2021 IEEE 12th Annual Ubiquitous Computing, Electronics and Mobile Communication (IEEE UEMCON), 2021*. (The paper will also be published in the IEEE Xplore Database as part of the IEEE UEMCON 2021 conference proceedings)

4. Cyprian Oton and M. T. Iqbal, "Load Analysis and Design of a stand-alone Solar PV Power System for a Secondary School in Nigeria," Presented at the *28th Annual Newfoundland Electrical and Computer Engineering Conference (NECEC 2019)*, St. John's, NL, Canada. November 19, 2019.

# Acknowledgments


- ❖ Almighty God
- ❖ My supervisor, Prof. M. Tariq Iqbal
- ❖ My family
- ❖ Niger Delta Development Commission (NDDC) of Nigeria for funding. (Grant No. NDDC/DEHSS/2016PGFS/AKS/002)
- ❖ School of Graduate Studies, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John’s NL, Canada.
- ❖ All my colleagues, friends, within and outside St. John’s

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Question?


Thank you!